Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

Issued March 21, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 48.

MILTON WHITNEY, Chief.

FERTILITY OF SOILS AS AFFECTED BY MANURES.

BY

FRANK D. GARDNER.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., June 24, 1907.

Sir: I have the honor to transmit a manuscript entitled Fertility of Soils as Affected by Manures, by Frank D. Gardner, in charge of Soil Management. It embodies the results of a uniform scheme of manurial treatments, as measured by the resulting increase in plant growth on soils collected from 220 fields in 23 States, located in the eastern half of the United States.

The increasing use of manures, and especially of commercial fertilizers, by the farmers of the United States is sufficient justification for careful investigations as to the relative efficiency of various forms of manures on different soils. You will find here a vast amount of data, treated in a manner commensurate with the importance of the subject. It should be of great value to all who are interested in the use of manures.

The manuscript has been gone over carefully with Assistant Secretary Hays, who concurs in my recommendation for its publication as Bulletin No. 48 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

Page.
Introduction 7
Object of the investigations 9
The soils 10
The method 10
Fertilizers used 13
Calculation of results 13
Arrangement and tabulation of results 15
Comparative efficiency of salts used separately and in combination 24
Nitrate of soda alone and with other salts 31
Sulphate of potash alone and with other salts 32
Acid phosphate alone and with other salts 32
Lime alone and with fertilizer salts 33
Relative efficiency of organic and chemical manures 37
Relative efficiency of all salts and combinations, when soils are grouped according to efficiency of PKN 38
Relative efficiency of salts when used alone and in combination 39
Relation of fertilizer requirements to character of soils 44
Relative efficiency of fertilizers by locality 46
Comparative fertility of soils 47
Relative response to fertilizers and expenditures for fertilizers 48
Average efficiency of fertilizer salts, by locality 50
Comparative efficiency of fertilizers, by soil series 51
Efficiency of fertilizer as related to soil texture 53
Natural fertility as related to responsiveness to fertilizers 53
Fertilizers and economy of water in plant growth 54
Summary 56

ILLUSTRATIONS.

Fig. 1. Percentage increase in growth of plants, attributable to various fertilizer treatments of five principal soil types of the Waycross area, Georgia 44
2. Percentage increase in growth of plants, attributable to various fertilizer treatments for all soils of Waycross area, Georgia, and Escambia County, Fla 45
3. Percentage gain in plant growth attributable to each of the salts P, K, N, and L when used alone 59
4. Relative efficiency of fertilizer ingredients by soil series, when the ingredients are used alone 52
5. Percentage increase in growth of plants attributable to fertilizer and accompanying increase per unit of water transpired. Average of 20 soils 55

FERTILITY OF SOILS AS AFFECTED BY MANURES.[a]

INTRODUCTION.

The use of manures as a means of increasing the growth of crops dates back to ancient times. At the time of the discovery of America, the North American Indians used dead fish as a manure for corn. The Peruvians have used guano since the beginning of their recorded history, and the Chinese have long recognized the value of all kinds of excrements as fertilizers. In the early part of the last century De Saussure established the existence of the mineral constituents of the soil in plants, and while he believed that they were essential to the life of plants, his contemporaries regarded them as nonessential, or at the best useful only as a kind of stimulant.

Justus Von Liebig, as a result of his investigations, published in 1843 a new edition of his notable work, "Chemistry in its Application to Agriculture and Physiology," in which it may be said he laid the foundation of the celebrated "mineral theory" of agriculture.

Prior to the time of Liebig the use of manures and fertilizers was purely an art, the beneficial results of which had not been satisfactorily explained. Liebig's mineral plant food theory, apparently so ample, and in time widely accepted, attributed the beneficial effect of fertilizers solely to the plant food constituents which were supplied to the growing plants, and thereby laid the foundation for the compounding of fertilizers to meet the needs of soils and crops. There soon sprang into existence a soil chemistry which had for its object an investigation of the stores of plant food in soils with a view to ascertaining the agricultural value of lands, as well as the character and amount of fertilizer, if any, that would give the largest net crop income per acre. It was soon learned that the soil constituents existed in various forms or compounds not all of which were available as plant food, and this led to a study of inexpensive methods of determining the available constituents, a study which has formed no small part of soil chemistry even down to the present time, with little indication that a method will ever be devised that will prove universally satisfactory for all soils and crops.

---

[a] A comparative study of the fertility of the soils of the central and eastern United States, as influenced by manures and fertilizers and measured by the paraffin-pot method.

So far as can be gleaned from the writings of soil investigators, only within recent years have any considerable number of them come to realize that there is no definite relation between the available plant food constituents of soils, as determined by mineral analysis, and their crop-yielding capacities. Neither had they arrived at that further realization that the crop-yielding capacity of a soil is dependent upon a complexity of factors, any one of which may be dominant, but all of which are concerned in large or small degree.

Arable soils contain the organic remains of previous crops together with excretions produced during their growth and are also filled with living forms. Their bacterial flora is diversified and the activities and processes which take place within the soil, physical, chemical, and biological, are exceedingly complex, and at present but imperfectly understood. It is the sum total of these activities and their products that determines largely the fitness of a soil for plants, rather than the variation in the character and composition of its mineral matter. While manure and fertilizers may often increase crop yields as a result of a direct supply of plant food or as a stimulant to the plants, there is now abundant evidence that their effect is rather the result of a direct action upon the soil, thereby changing its relation to plants. Complex and imperfectly understood as is this action, it is a more satisfactory explanation of the benefits derived from fertilizers than the idea that the inconsequential amounts of nitrogen, potash, and phosphorus applied, as compared with the larger stores of those elements already in the soil, should be directly responsible for such marked increase in growth as frequently follows the application of fertilizers.

The prime object of manuring the soil, whether with stable manure, green manure, or commercial fertilizers, is to increase its crop-yielding capacity, and in order to justify the practice the resulting increase in product must be more than enough to offset the cost of the fertilizers applied. That is to say, the beneficial effect on the present and succeeding crops must be sufficient to compensate for the cost of the fertilizers and give a profit on the capital so invested.

The first noteworthy use of commercial fertilizers in the United States was in 1848, during which year there was imported 1,000 tons of guano. This was followed the succeeding year by twenty times that quantity, after which date the importation steadily increased until 1880, when it reached its maximum and began to fall off because of a failing supply. Other materials, notably sodium nitrate from Chile and the potash salts from Germany, have taken the place of the failing supply of guano, and these, together with the development of our phosphate mines, the use of cotton-seed meal, and the utilization of slaughterhouse by-products, have met the continually increasing demand for commercial fertilizers by our farmers. According to our census reports, the expenditure for fertilizers in the United States in 1880 was $28,500,000. Ten years later it was $38,500,000, and in 1900 it reached the significant sum of $54,750,000. There seems little doubt that this rate of increase in the use of fertilizers will continue for some time to come, and the subject is one of sufficient national importance to justify careful investigations.

OBJECT OF THE INVESTIGATION.

The object of this investigation is not for the purpose of explaining how fertilizers act nor of studying the relation of the composition of the soil to the beneficial effect of the fertilizer when applied to it, but rather to compare the effects of several high-grade standard fertilizer ingredients, lime, stable manure, and cowpea vines when applied under like conditions to a large number of soils, collected from widely separated areas and representing a wide range in soil texture, type, origin, and crop adaptation. By making a comparative test of a large number of soils it was thought that there might be established a relation between the manurial requirements and the origin, formation, type, or crop adaptation of the soil.

While there has been recorded in agricultural literature, in the aggregate, a large number of field tests of fertilizers on a great variety of soils, representing nearly every State in the eastern half of the United States, it is impossible to make a satisfactory comparison of the results obtained, because of the innumerable details in which the conditions of the tests do not agree. The variation in the amount, class, kind, and composition of the fertilizer used, the time and manner of its application, the test crop used, and the weather conditions which prevailed form such a wide range of possible combinations that it is rare to find two tests that are strictly comparable.

In the present investigation the same variety of wheat was used throughout as the test crop, and all of the conditions for growth, excepting the manurial treatments to be tested, were maintained as nearly uniform as possible. With the same fertilizer ingredients, in like form and used in the same combinations, for a crop common to all, the results obtained from this large number of soils are strictly comparable, and far exceed in number any similar tests that can be brought together on such a basis.

Mention should also be made of the fact that all tests reported in the following tables under areal surveys—and they constitute fully four-fifths of them—were made for the further purpose of gaining practical knowledge concerning the manurial requirements of the principal soil types as established by the soil survey parties and with the ultimate object of determining what manures or fertilizers would give best results on the soils. The results of all such tests are reported in general terms in the soil survey reports for the respective areas in which they occur.

THE SOILS.

The soils tested in this investigation, 220 in number, represent 90 types, half that number of soil series, and many geological formations. The samples were taken from twenty-three States, extending from the Mississippi River to the Atlantic seaboard and from Rhode Island to Texas. With the exception of a limited number of miscellaneous samples, the greater number were collected from areas that were in process of being surveyed by the Bureau of Soils during the summer of 1905, and the following winter, and are representative of the soils of those areas rather than the vast expanse of country included in the twenty-three States above mentioned. Each sample, being a composite, made up of fifteen or twenty small samples, taken from different parts of the same field, is representative of the field from which it is taken as well as the type which it represents. The samples were placed in strong grain bags and shipped to the Bureau's headquarters, where they were at once transferred to covered galvanized iron cans for storage. In this way the original condition and original moisture content were, as far as practicable, maintained until they could be tested. This is important in relation to the test, for it has been found by experience that as a result of long storage and resulting air-dry condition soils become more productive and are usually less responsive to fertilizers than when such a change is prevented.

THE METHOD.

The paraffin-pot method, described in Circular No. 18 of this Bureau and in the appendix to Farmers' Bulletin No. 257 of the United States Department of Agriculture, was employed in these tests, and while it is not designed to supersede field tests, results obtained with it, when compared with results obtained on the same soils at the agricultural experiment stations in Rhode Island,[a] New York, Ohio,[b] Iowa, Missouri, and North Carolina, show that it will indicate the manurial requirements of soils for general farm crops with a fair degree of accuracy. It is also admirably adapted to an investigation of the character described in the following pages.

The soil to be tested is thoroughly pulverized by crushing all lumps, and if containing stone or gravel this is removed by sifting. The sample is then thoroughly mixed and equal amounts weighed into granite-ware pans, where they receive their respective applications of manure or fertilizers and are made up to their optimum water content with distilled water. After remaining in the pans for about a week, being occasionally wet with distilled water, and frequently stirred in order to secure a thorough incorporation of the fertilizer and a good soil condition, it is ready to pot and plant. Five small wire-gauze pots are used for each treatment. About 350 grams of soil is then placed in each pot, uniformly packed, and planted with six selected germinated kernels of wheat, after which the pots are dipped in melted paraffin, which not only forms an intimate contact with the soil but makes the pot water tight. The soil is then covered with a thin layer of washed quartz sand and the pot and contents weighed and weight recorded. The pots are next placed in trays and given a favorable exposure in the greenhouse for three or four days or until the plants attain a height of about 1½ inches, at which time the pots are sealed. The sealing consists of covering the tops with paraffined paper disks in which are slits through which the plants grow. The disks are sealed to the sides of the pots by means of melted paraffin. The loss of water by direct evaporation from the soil is in this way reduced to a negligible quantity.

---

[a] See Bul. 109 of the Rhode Island Expt. Sta.

[b] See Buls. Nos. 167 and 168 of the Ohio Agricultural Expt. Sta.

During the growing of the plants, which usually continues from eighteen to twenty-one days from the date of sealing, the pots are weighed at intervals of two or three days and watered with distilled water in order to retain a favorable moisture content for plant growth. By this method the loss of water or the amount transpired by the plants may be ascertained periodically, and at the end of the experiment the total amount of water given off through the plants of each pot obtained for comparison with the growth and green weight of the plants, which is ascertained by cutting and weighing the plants at the time the experiment is concluded. All conditions of the experiment are so carefully controlled that the average result of five pots rarely differs more than 5 per cent from the average result of any other five pots that have been treated throughout in precisely the same manner (see Table I). Differences which occur beyond this amount may therefore safely be attributed to the different manurial treatments which have been given. This method has several advantages over the growing of plants in open and porous pots. The method of coating the soil with paraffin prevents any accumulation of roots between the soil and the receptacle, a trouble which is common in pot experiments. The complete sealing up of the soil also enables the experimenter to determine the amount of water which the plant has actually used and transpired in its process of growth, and this, together with the small size of the pots, enables the moisture content and its fluctuations to be carefully controlled.

On good soils, or as a result of favorable treatment, plants are produced in the little pots in twenty-five days or less time, the green weight of which sometimes equals or exceeds 1 per cent of the weight of the soil in which they grew. Such plants are approximately 85 per cent water; they have transpired about 100 units of water for each unit of green matter produced, and their dry matter is relatively richer in mineral constituents and nitrogen than that of mature plants. On this basis, an acre foot of soil, weighing 3,500,000 pounds, would produce 35,000 pounds of green matter, requiring for its production the equivalent of 17½ inches of rainfall. This green matter would be equivalent to 5,900 pounds of air-dry material, or about 50 bushels of wheat and 1½ tons of straw to an acre. While the removal of green matter equal to 1 per cent of the soil in the little pots is somewhat above the average, it serves as an illustration of the heavy draft made upon the soil in a very short time, a draft, as regards moisture and mineral constituents, although part of the latter comes from the seed, greater than that which takes place under field conditions by the removal of a large mature crop, assuming that the removal takes place to a depth not greater than 1 foot, which for wheat and similar crops would be approximately correct, and providing also the movement of plant food by capillarity from below 1 foot be ignored.

TABLE I.—*Actual transpiration in grams for each of twenty pots, on three soils, under uniform treatment, and the percentage variation from the average for each pot, also average percentage variation of each group of five pots.*

Leonardtown loam. Corn.			Cecil clay—poor.			Leonardtown loam.		
Transpiration.	Variation.		Transpiration.	Variation.		Transpiration.	Variation.	
For each pot.	For each pot.	For 5 pots.	For each pot.	For each pot.	For 5 pots.	For each pot.	For each pot.	For 5 pots.
Grams.	*Per cent.*	*Per cent.*	*Grams.*	*Per cent.*	*Per cent.*	*Grams.*	*Per cent.*	*Per cent.*
69.9	− 5.5	−0.9	39.3	+10.1	−2.8	87.5	+ 0.4	+3.3
77.6	+ 4.9		25.7	−28.0		90.5	+ 3.9	
58.7	−20.1		37.7	+ 5.6		89.1	+ 2.2	
83.5	+12.8		34.8	− 2.5		98.4	+12.9	
76.5	+ 3.3		35.9	+ 0.6		84.8	− 2.6	
59.1	−20.2	−3.0	35.8	+ 0.3	+4.1	89.9	+ 3.2	+1.6
72.1	− 2.6		37.3	+ 4.4		99.2	+13.9	
79.2	+ 7.0		38.6	+ 8.1		87.7	+ 0.7	
73.9	− 0.2		35.4	− 0.8		80.5	− 7.6	
74.1	+ 0.8		38.9	+ 8.9		85.2	− 2.2	
82.3	+11.1	+2.2	38.8	+ 8.6	+0.8	79.8	− 8.4	−2.7
66.8	− 9.8		33.6	− 5.9		79.5	− 8.7	
70.6	− 4.6		37.8	+ 5.9		86.1	− 1.1	
68.9	− 6.9		38.1	+ 6.7		88.8	+ 1.9	
89.9	+21.4		31.7	−11.2		89.5	+ 2.7	
84.3	+13.8	+2.0	34.7	− 2.8	−2.5	82.4	− 5.4	−2.1
79.0	+ 6.7		32.3	− 9.5		83.0	− 4.7	
76.4	+ 3.2		39.8	+11.2		94.3	+ 8.2	
68.3	− 7.7		36.9	+ 3.4		87.4	+ 0.3	
69.7	− 5.8		31.2	−12.6		79.3	− 8.9	

FERTILIZERS USED.

In this investigation the tests were confined to the use of high-grade, standard fertilizing materials, consisting of nitrate of soda, sulphate of potash, and acid phosphate, together with air-slaked lime, well-decomposed stable manure, and green cowpea vines. These ingredients were applied to the soil separately and in various combinations as follows:

Treatment and rate per acre.

1. Untreated.
2. Manure, 10 tons.
3. Lime, 1 ton.
4. Nitrate of soda, 200 pounds.
5. Sulphate of potash, 200 pounds.
6. Acid phosphate, 200 pounds.
7. Nitrate of soda and sulphate of potash, 200 pounds each.
8. Nitrate of soda and acid phosphate, 200 pounds each.
9. Sulphate of potash and acid phosphate, 200 pounds each.
10. Nitrate of soda, sulphate of potash, and acid phosphate, 200 pounds each.
11. Same, plus lime, 2,000 pounds.
12. Cowpea vines 5 tons, lime 2,000 pounds.

The rate of application is based on the weight of an acre of soil to the depth of 7 inches, which is approximately 2,000,000 pounds. The fertilizers were applied in solution, and the lime, manure, and cowpea vines in bulk, each being finely ground.

CALCULATION OF RESULTS.

While this report combines the results of more than 13,000 pots, individual record of which has been made, the results were reported on forms, of which the following is a sample:

[Can 101.]

Actual transpiration and green weight and relative transpiration and green weight of 30 wheat plants on the basis of 100 for the untreated soil.

Soil: Norfolk Sandy Loam. Locality: Waycross, Ga.
Planted: April 5. Sealed April 10. Disctd.: April 28. Basket Nos.: 2066–2125.

Number.	Treatment and parts per million.[a]	Transpiration, 18 days.	Green weight.	Relative variation by—	
				Transpiration.	Green weight.
1	Untreated	757.6	7.0	100	100
2	Manure 10,000	1295.2	14.2	171	203
12	Cowpeas 5,000, lime 1,000	1135.7	13.6	150	194
10	Nitrate of soda, potassium sulphate, and acid phosphate 100 each	1160.3	11.5	153	164
11	Same + lime 1,000	1090.1	11.0	144	157
7	Nitrate of soda and potassium sulphate 100 each	1047.2	10.8	139	154
8	Nitrate of soda and acid phosphate 100 each	997.6	9.6	132	137
4	Nitrate of soda 100	1053.0	9.5	139	136
5	Potassium sulphate 100	925.9	8.0	122	114
9	Potassium sulphate and acid phosphate 100 each	833.6	8.0	110	114
3	Lime 1,000	803.0	7.0	106	100
6	Acid phosphate 100	651.9	6.5	86	93

[a] Parts per million multiplied by 2 equals the pound rate per acre on the basis of 2,000,000 pounds as the weight of an acre of soil 7 inches deep.

On this form are given the total transpiration and total weight of green plants for each treatment, consisting of five pots. The transpiration and the green weight of plants for each treatment are entered in the third and fourth columns, respectively, while the relative transpiration and weight, based on 100 for the untreated soil, are given in the fifth and sixth columns and are merely computed from the actual transpiration and weight in order to convert the comparison to a percentage basis and make it more simple.

The variation by transpiration, while a good indication of the relative growth and effect of the treatments, frequently gives a range of lesser magnitude than the actual growth of plants. Plants that have made a marked increase in growth as a result of soil treatment usually contain a higher percentage of water than untreated ones and therefore show a slightly lesser variation by dry, or water-free, weight than by green weight. See Table II, which follows. The increase in growth is also accompanied by an improvement in condition which can only be measured by appearance, but which will usually prove an advantage to the better plants if grown to maturity. The results given in this bulletin are all based on the actual green weight of plants, the weighings being made immediately upon cutting the plants and under uniform conditions.

TABLE II.—*Percentage gain or loss attributable to various fertilizer treatments on four soils.*

[P=acid phosphate. K=sulphate of potash. N=nitrate of soda. L=lime. M=stable manure.]

A.—BASED ON GREEN WEIGHT OF PLANTS GROWN ON UNTREATED SOILS.

Soil.	Green weight of plants grown on untreated soils.	Percentage gain or loss attributable to—									
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.
	Grams.										
Cecil clay, good	8.8	0	−2	−4	......	9	14	−4	5	....	9
Cecil clay, poor	8.8	−1	1	0	......	−6	7	5	6	....	−14
Leonardtown loam, good	8.3	16	7	47	......	41	47	46	10	....	17
Leonardtown loam, poor	6.5	−7	15	8	......	0	12	22	1	....	24
Average	7.6	2	5	13	......	11	20	17	5	....	9

B.—BASED ON DRY WEIGHT OF PLANTS GROWN ON UNTREATED SOILS.

Soil.	Dry weight of plants grown on untreated soils.	Percentage gain or loss attributable to—									
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.
	Grams.										
Cecil clay, good	1.60	−1	−11	−9	......	−1	3	13	−5	....	−11
Cecil clay, poor	1.55	−3	−4	0	......	−8	8	5	−1	....	−17
Leonardtown loam, good	1.20	13	4	37	......	25	47	36	8	....	18
Leonardtown loam, poor	1.22	2	18	5	......	0	9	24	6	....	9
Average	1.39	3	2	8	......	4	17	19	2	....	0

ARRANGEMENT AND TABULATION OF RESULTS.

Table III, which follows, gives the actual green weight of plants grown on the untreated soils and the percentage increase or decrease in growth, the latter indicated by the minus (–) sign, resulting from the various fertilizer ingredients and combinations. The data are arranged by States, areas, and types and averages are given for areas and for types within areas. The symbols at the head of the columns are used for the sake of brevity. **P** stands for acid phosphate; **K** for sulphate of potash; **N** for nitrate of soda; **L** for air-slaked lime; **M** for well-rotted stable manure, and **Cv** for green cowpea vines. The ingredients and rate of application are given in the preceding form. All data resulting from the tests are embodied in Table III. Marked variations from the general trend are exceptional and most frequently occur with manure or cowpea vines. These substances have occasionally given negative results apparently as a result of decomposition products from which the soil did not have sufficient time to recover prior to the planting of the seed. The blanks in the table indicate no tests for the ingredients or combinations heading the columns in which they occur. Practically all such omissions occurred in miscellaneous samples which were tested by the Bureau parties at several of the State experiment stations. Table III gives the results for 220 soils and from these results many tabulations were made, parts of which are given on subsequent pages. The arrangement and segregation of data in subsequent tables are for the purpose of a further comparative study of the facts as well as to enable the reader to verify statements that may follow in the text, although a number of facts are given from tabulations other than those which follow.

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications.*

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to–										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
WISCONSIN.												
Portage County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Miami stony sand	9.9	6	13	11	– 3	11	21	22	– 3	19	47	8
Miami sand	6.0	7	15	33	5	24	29	39	7	43	80	– 4
Miami sandy loam	9.0	4	8	2	– 1	10	14	3	4	21	29	12
Marshall gravelly loam	11.0	– 1	– 2	14	2	3	16	4	2	3	36	14
Marshall sand	8.4	7	9	31	13	23	32	35	11	8	34	3
Portage silt loam	10.0	–11	– 9	– 6	– 1	–10	– 3	3	5	10	21	10
Portage silt loam	8.7	2	–16	– 2	5	– 9	10	1	9	–14	42	–14
Average for area	9.0	2	3	12	3	7	17	15	5	13	41	4
MISSOURI.												
Crawford County:												
Clarksville silt loam	6.6	26	15	17	27	25	15	7	14	1	43	32
Wabash silt loam	7.6	–11	1	– 3	– 2	3	– 5	– 1	0	2	23	24
Clarksville stony loam	14.6	4	3	– 2	– 9	2	11	3	– 3	– 2	–10	13
Average for area	9.6	6	6	4	5	10	7	3	4	0	19	23

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
MISSOURI—continued.												
Scotland County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Shelby silt loam	9.6	7	24	14	22	17	32	28	11	28	69	30
Miscellaneous:												
Loess, McBain County	7.8	8	22	28	26	26	47	50	19	....	23	35
Clay loam, Salem	7.0	......	......	.....	25	50	60	68	25	50	57	35
Silt loam, Columbia	5.9	......	......	.....	29	54	44	61	7	66	34	50
INDIANA.												
Newton County:												
Marshall fine sandy loam	6.3	5	12	9	0	5	12	−4	−12	−1	60	−2
Marshall loam	7.6	17	22	17	20	14	21	16	22	21	77	34
Clyde fine sand	12.6	−21	−2	−14	−8	−23	13	−17	−12	−7	32	−4
Average for area	8.8	0	11	4	4	−1	15	−2	−1	4	56	9
Tippecanoe County:												
Marshall silt loam	7.2	4	1	6	10	.....	3	12	−7	6	−2	4
Marshall loam	7.5	−3	2	7	−6	4	18	6	−3	7	42	−2
Miami silt loam	5.6	30	21	28	26	58	46	58	17	35	71	30
Average for area	6.8	10	8	14	10	31	22	25	2	16	37	11
OHIO.												
Westerville area:												
Miami black clay loam	8.3	−11	6	−2	9	13	7	8	1	11	22	5
Miami clay loam	6.1	11	5	15	3	27	11	13	7	11	15	45
Miami loam	8.6	−8	3	−2	−3	1	8	−5	2	2	48	15
Average for area	7.8	−3	5	4	3	14	9	5	3	8	28	22
Miscellaneous:												
Volusia silt loam, Wooster	5.8	0	.....	.....	14	47	46	62	21	76	52	......
Miami clay loam, Germantown	7.1	4	.....	.....	6	24	30	27	9	47	10	22
Miami clay loam, Strongsville	....	−4	−5	12	−9	−6	−6	−6	30	....	9	......
NEW YORK.												
Tompkins County:												
Dunkirk clay loam	9.0	0	9	13	−1	6	23	11	−14	12	68	−5
Dunkirk clay loam	4.5	−18	4	55	−5	27	47	42	29	....	33	54
Average for type	6.8	−9	7	34	−3	17	35	27	8	....	51	25
Dunkirk loam	8.4	−4	2	15	−1	16	20	12	−7	11	46	0
Miami stony loam	9.6	4	1	1	−4	−8	6	11	0	7	36	26
Average for area	7.9	−5	4	21	−3	10	24	19	2	10	46	19
Binghamton area:												
Dunkirk gravelly sandy loam	6.6	4	1	11	4	20	16	1	26	27	29	69
Dunkirk gravelly loam	10.6	9	9	1	−8	0	9	7	−3	−11	20	−9
Wabash loam	10.6	−1	11	5	16	12	22	26	10	15	31	10
Average for area	9.3	4	7	6	4	11	16	11	11	10	27	23
Other localities in State:												
Volusia silt loam	5.4	2	15	13	11	8	38	20	9	32	51	29
Volusia silt loam	4.8	−2	15	34	15	21	53	35	15	62	81	......
Volusia silt loam	6.6	4	22	10	11	4	19	23	8	15	77	13
Dunkirk clay loam	8.9	16	29	20	31	10	21	28	19	22	17	28
Dunkirk clay loam	10.2	11	11	18	−5	−6	6	5	8	0	17	21

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
PENNSYLVANIA.												
Montgomery County:	*Grams.*	*P. ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P.ct.*	*P. ct.*	*P.ct.*	*P. ct.*
Hagerstown loam	10.3	13	− 2	1	11	13	6	9	6	23	20	29
Penn silt loam	12.3	8	12	8	11	11	24	13	− 8	4	24	36
Lansdale silt loam	9.9	0	23	1	27	− 7	31	7	19	17	9	30
Chester loam	7.8	0	9	4	21	18	15	27	4	33	13	8
Average for area	10.1	5	10	4	18	9	19	14	5	19	17	24
RHODE ISLAND.												
The State:												
Miami silt loam, Kingston	3.6	− 8	−19	−14	28	22	22	31	133	111	39	......
Miami stony loam, Middleton	7.8	......	......	......	......	......	......	18	9	41	......	......
Miami stony loam, Jamestown	5.8	......	......	......	......	......	......	24	60	94	......	......
Miami stony loam, Curtis Corners	6.7	......	......	......	......	......	......	7	5	43	......	......
Miami stony loam, Woonsocket	9.1	......	......	......	......	......	......	10	10	17	......	......
Miami stony loam, Little Compton	15.4	......	......	......	......	......	......	5	0	8	......	......
Miami stony loam, Ashaway	5.6	......	......	......	......	......	......	4	21	35	......	......
Average for type	8.4	......	......	......	......	......	......	11	18	40	......	......
Gloucester stony loam, East Greenwich	8.7	......	......	......	......	......	......	15	2	37	......	......
Gloucester stony loam, Chepachet	8.5	......	......	......	......	......	......	4	9	21	......	......
Gloucester stony loam, Tarkiln	11.4	......	......	......	......	......	......	3	0	0	......	......
Gloucester stony loam, Foster	8.5	......	......	......	......	......	......	2	25	14	......	......
Gloucester stony loam, Greene	7.2	......	......	......	......	......	......	−22	8	30	......	......
Average for type	8.9	......	......	......	......	......	......	0	9	20	......	......
Alton stony loam, Hope Valley	5.5	......	......	......	......	......	......	34	38	54	......	......
Alton stony loam, Wickford	4.7	......	......	......	......	......	......	51	− 2	51	......	......
Average for type	5.1	......	......	......	......	......	......	43	18	53	......	......
Warwick sandy loam, Alton	7.1	......	......	......	......	......	......	41	− 8	42	......	......
Warwick sandy loam, Barrington	7.2	......	......	......	......	......	......	23	28	42	......	......
Average for type	7.2	......	......	......	......	......	......	32	10	42	......	......
Average for area	7.9	......	......	......	......	......	......	15	14	35	......	......
VIRGINIA.												
Louisa County:												
Cecil sandy loam	7.2	24	5	13	31	13	27	30	5	39	25	57
Cecil loam	4.6	36	47	75	26	75	100	102	71	153	63	158
Average for area	5.9	30	26	44	28	44	64	66	38	96	44	108
Hanover County:												
Wickham sandy loam	7.5	− 3	5	11	−1	10	16	36	9	35	31	−12
Norfolk sandy loam	7.5	3	11	20	16	17	35	30	− 1	47	44	− 8
Average for area	7.5	0	8	16	8	14	26	33	4	41	38	10

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
VIRGINIA—continued.												
Appomattox County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Cecil clay	12.9	......	.....	6	−13	4	12	2	− 1	2	− 3	24
Cecil clay, Pocahontas field	11.7	− 3	4	− 3	− 2	.....	.....	9	− 6	7	− 2	7
Cecil clay, Mitchell field	13.2	− 7	.....	4	3	.....	.....	6	5	− 4	2	6
NORTH CAROLINA.												
New Hanover County:												
Norfolk sand	4.1	37	41	122	61	124	131	151	66	154	241	144
Norfolk fine sand	6.4	3	9	37	20	45	51	63	16	70	94	37
Norfolk fine sandy loam	7.3	3	3	22	3	20	33	29	8	31	57	34
Portsmouth fine sand	3.0	13	30	77	40	87	117	110	70	173	130	230
Average for area	5.2	14	21	65	31	69	83	88	40	107	131	111
Miscellaneous:												
Cecil clay (good), Statesville	8.8	0	− 2	− 4	.....	9	14	− 4	5	....	9	......
Cecil clay (poor), Statesville	8.8	− 1	1	0	.....	− 6	7	5	6	....	−14	3
Cecil clay, Iredell test farm	4.5	86	34	42	99	97	35	105	45	105	90	......
Cecil sandy loam, Raleigh	4.1	20	31	30	29	23	39	49	52	103	53	54
Iredell clay loam, Statesville	5.2	7	21	16	19	9	28	34	− 1	28	33	......
Norfolk fine sandy loam, Edgecombe	4.8	44	42	63	33	52	71	56	25	77	66	......
Norfolk fine sandy loam, Tarboro	3.0	25	22	42	29	51	59	63	1	70	38	78
Porters clay, Asheville	5.8	− 6	− 2	29	−14	24	40	19	10	53	8	15
Porters clay, Biltmore	12.4	11	15	18	16	26	11	25	31	26	61	24
Porters sandy loam, Blantyre	4.5	4	44	20	31	20	51	24	43	22	61	31
Portsmouth sand, Pinehurst	4.8	42	26	42	35	43	38	56	26	46	41	45
Portsmouth silt loam, Chowan County	4.5	2	19	14	16	23	62	62	19	57	46	74
Silt loam, Union County	4.6	− 4	0	32	19	19	21	42	4	51	28	......
Tobacco soil, Wake County	4.7	9	11	28	20	17	22	30	11	16	.....	......
SOUTH CAROLINA.												
York County:												
Cecil sand	3.9	−15	− 8	26	28	8	20	54	8	71	90	60
Cecil sandy loam	7.0	40	3	28	− 9	0	40	34	33	41	76	58
Iredell clay loam	7.7	0	6	19	1	6	16	18	3	17	51	19
Average for area	6.2	8	0	24	7	5	25	35	15	43	72	46
Cherokee County:												
Cecil clay	7.4	− 4	− 6	36	− 2	26	39	35	4	44	42	12
Cecil silt loam	6.6	2	1	52	9	47	52	48	39	56	81	74
Cecil fine sandy loam	5.9	− 3	7	46	− 1	46	46	52	29	68	88	123
Cecil sandy loam	6.9	−12	28	35	9	33	60	58	4	65	71	5
Iredell clay loam	9.1	− 3	7	32	1	27	46	27	14	42	36	7
Average for area	7.2	− 4	7	40	3	36	49	44	18	55	64	44
Lancaster County:												
Cecil silt loam	7.3	......	.....	75	15	63	61	67	8	73	10	111
Miscellaneous:												
Orangeburg sandy loam, St. Matthews	11.8	0	− 2	15	5	16	14	26	19	28	25	17
Portsmouth sandy loam, Darlington	5.3	......	.....	13	9	35	26	30	40	105	44	138

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
TENNESSEE.												
Henderson County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Lexington silt loam	7.5	1	1	36	5	16	44	36	5	57	72	17
KENTUCKY.												
McCracken County:												
Memphis silt loam	5.0	− 3	3	39	8	25	42	42	18	48	70	− 2
GEORGIA.												
Waycross area:												
Norfolk sand, 12 miles west Waycross	5.5	− 9	24	45	27	49	65	72	64	109	124	118
Norfolk sand, 4½ miles SE. Waycross	5.6	− 4	30	61	18	45	50	57	20	121	114	132
Norfolk sand, 3½ miles NW. Waltertown	6.1	− 2	− 5	36	5	22	41	24	34	55	77	65
Average for type	5.7	− 5	16	47	17	39	52	51	39	95	105	105
Norfolk fine sand, 3 miles W. Waycross	6.1	7	15	55	23	49	69	74	34	84	102	107
Norfolk fine sand, 8 miles SE. Waycross	6.0	5	8	53	− 2	18	38	50	27	32	113	107
Norfolk fine sand, 2 miles W. Waycross	7.4	− 9	− 8	− 3	− 6	−12	0	14	6	25	28	36
Average for type	6.5	1	5	35	5	18	36	46	22	47	81	83
Norfolk Sandy loam, 2½ miles N. Waycross	7.0	− 7	14	36	14	37	54	64	0	57	103	94
Norfolk sandy loam, 3 miles NW. Waycross	6.5	11	15	54	15	77	102	85	35	100	109	109
Norfolk sandy loam, 2½ miles SW. Elsie	5.0	0	16	20	3	15	42	25	−9	43	54	42
Average for type	6.2	1	15	37	11	43	66	58	9	67	89	82
Norfolk fine sandy loam, 5¼ miles W. Waycross	7.5	17	28	60	23	63	83	73	40	89	113	113
Norfolk fine sandy loam, 3 miles E. Waycross	7.9	1	5	29	6	21	38	24	22	35	96	67
Norfolk fine sandy loam, 4 miles N. Manor	3.9	11	29	74	35	51	79	86	64	105	150	176
Average for type	6.4	10	21	54	21	45	67	61	42	76	120	119
Portsmouth fine sand, 5½ miles SE. Waycross	5.2	6	21	73	31	92	104	77	29	117	150	148
Portsmouth fine sand, 1 mile S. Needham	5.2	1	15	50	26	75	80	90	92	153	219	175
Portsmouth fine sand, 1 mile S. Glenmore	5.5	2	18	33	24	33	29	71	20	75	64	109
Average for type	5.3	3	18	52	27	67	71	79	47	115	144	144
Average for area	6.0	2	15	45	16	42	59	59	32	80	108	107
FLORIDA.												
Escambia County:												
Portsmouth sand	8.3	2	5	12	5	18	11	11	48	48	47	35
Norfolk sand	5.4	16	18	13	11	11	13	11	46	74	83	107
Norfolk sand	5.9	5	32	45	15	20	84	46	24	55	94	97
Norfolk sand	7.2	4	19	33	9	16	41	22	29	23	66	65
Average for type	6.2	8	23	30	12	16	46	26	33	51	81	90

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
FLORIDA—continued.												
Escambia County—Cont'd.	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Norfolk fine sandy loam	8.4	− 7	14	15	8	−12	−4	11	35	14	32	51
Norfolk fine sandy loam	5.5	10	12	−5	32	39	30	32	45	82	32	85
Norfolk fine sandy loam	3.3	24	36	27	33	48	12	48	136	130	90	136
Average for type	5.7	9	21	12	24	25	13	30	72	75	51	91
Average for area	6.3	8	19	20	16	20	27	26	52	61	63	82
ALABAMA.												
Lee County:												
Cecil sandy loam	8.6	1	9	14	− 2	8	31	15	10	28	.....	58
Cecil sandy loam	5.6	−11	− 7	29	−11	13	11	43	13	52	43	......
Average for type	7.1	− 5	1	21	− 7	10	21	29	12	40	.....	......
Norfolk sand	6.8	9	10	40	3	63	77	62	57	103	107	160
Norfolk sand	4.7	− 1	− 1	30	− 3	21	40	35	50	135	108	143
Average for type	5.8	4	4	35	0	42	58	48	53	119	108	151
Norfolk sandy loam	6.1	−14	4	42	15	37	43	46	11	64	42	104
Norfolk sandy loam	7.7	12	19	55	20	50	53	63	19	87	61	164
Average for type	6.9	− 1	12	48	18	43	48	54	15	75	52	134
Norfolk coarse sand	5.3	− 7	15	48	8	34	49	50	5	70	59	101
Norfolk coarse sand	6.4	−12	0	20	− 2	3	13	25	22	23	33	41
Average for type	5.8	− 9	7	34	3	18	31	37	13	46	46	71
Average for area	6.4	− 3	6	35	3	28	40	42	23	70	65	110
Miscellaneous:												
Clarksville clay loam, Florence	11.5	......	.....	6	− 4	− 4	3	19	− 1	10	−15	−13
Clarksville silt loam, Florence	9.5	......	.....	25	17	13	17	20	4	15	− 3	30
Orangeburg clay, Kings farm	10.3	3	6	17	6	40	19	19	16	35	32	26
Orangeburg clay, Ford's farm	9.1	22	24	42	37	45	34	67	20	55	49	35
Orangeburg sandy loam, Rawl's farm	8.1	6	− 5	4	5	9	2	12	21	17	17	20
Orangeburg sandy loam, Marion	4.8	14	7	25	19	59	28	69	12	69	37	60
MISSISSIPPI.												
Pontotoc County:												
Lufkin clay	6.4	8	8	28	6	22	14	28	6	31	9	48
Lufkin silt loam	5.4	41	44	52	32	39	44	50	63	56	37	78
Orangeburg clay	6.6	− 9	3	18	0	14	27	45	− 3	47	18	32
Orangeburg sandy loam	7.6	17	− 2	28	2	10	21	26	6	39	25	24
Monroe silt loam	8.0	− 4	− 6	13	6	23	25	14	9	18	29	39
Average for area	6.8	10	9	28	9	22	26	32	16	38	24	44
Montgomery County:												
Orangeburg fine sandy loam	7.5	24	20	43	13	53	53	48	24	64	60	60
Lintonia loam	8.5	7	17	29	27	17	26	22	24	16	30	48

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
MISSISSIPPI—continued.												
Montgomery Co.—Cont'd.	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Memphis silt loam.....	10.6	−13	− 3	− 2	−16	0	7	1	−1	16	−4	6
Memphis silt loam.....	9.5	−16	− 9	0	− 8	− 7	8	− 5	−5	3	−5	11
Memphis silt loam.....	8.6	−13	6	12	3	10	14	13	6	9	6	34
Memphis silt loam.....	10.2	− 3	− 2	−15	− 6	5	9	12	1	20	18	28
Memphis silt loam.....	11.2	−10	− 7	−11	−10	−13	5	8	0	−3	5	9
Memphis silt loam.....	7.0	7	9	14	4	14	12	14	13	17	36	40
Average for type....	9.5	− 7	− 2	− 2	− 6	0	11	7	3	11	9	21
Average for area....	9.3	− 1	3	8	0	9	18	14	8	18	18	30
LOUISIANA.												
Caddo Parish:												
Caddo fine sandy loam.	4.4	18	18	86	25	16	84	36	18	52	20	186
Caddo fine sandy loam.	5.0	−10	4	33	− 4	2	62	4	8	72	44	148
Caddo fine sandy loam.	8.8	− 7	5	7	− 8	15	2	9	8	14	6	41
Caddo fine sandy loam.	6.0	6	17	26	− 4	20	12	8	19	16	79	23
Average for type....	6.0	2	11	38	2	13	40	14	13	39	37	100
Miller fine sand........	5.8	12	12	38	3	24	21	19	22	34	81	48
Miller fine sand........	7.3	21	26	10	21	38	17	1	14	16	43	36
Average for type....	6.6	17	19	24	12	31	19	10	18	25	62	42
Norfolk fine sand......	3.7	− 3	51	62	65	54	65	51	41	113	146	195
Norfolk fine sand......	5.4	21	19	41	5	61	62	56	39	80	92	98
Norfolk fine sand......	5.3	15	21	32	36	32	61	59	9	74	28	80
Average for type....	4.8	11	30	45	35	49	63	55	30	89	89	124
Norfolk fine sandy loam................	8.7	4	9	7	9	17	21	9	0	30	9	25
Norfolk fine sandy loam................	9.6	− 8	9	13	−19	8	13	− 1	6	19	22	1
Norfolk fine sandy loam................	5.6	− 3	20	35	19	76	44	33	28	54	54	52
Norfolk fine sandy loam................	7.9	1	− 5	−10	3	16	44	35	2	56	18	47
Average for type....	8.0	− 1	8	11	3	29	31	19	9	40	26	31
Orangeburg fine sand..	7.4	8	10	21	8	15	28	21	20	28	15	28
Orangeburg fine sand.	5.0	−22	−10	−10	−10	20	14	28	12	50	114	124
Average for type....	6.2	− 7	0	6	− 1	18	21	25	16	39	115	76
Orangeburg fine sandy loam................	6.5	3	3	0	0	10	7	15	7	15	20	26
Orangeburg fine sandy loam................	5.0	0	6	10	22	20	30	32	0	44	34	96
Average for type....	5.7	2	5	5	11	15	19	24	4	30	27	61
Average for area....	6.3	3	13	24	10	26	35	24	15	45	54	74
ARKANSAS.												
Prairie County:												
Calhoun clay..........	8.3	12	12	14	12	16	16	26	18	27	4	13
Crowley silt loam......	7.1	− 8	0	9	9	0	−2	7	36	60	19	38
Crowley silt loam......	10.1	− 1	3	0	− 6	− 5	−2	3	2	5	7	9
Crowley silt loam......	7.0	0	10	43	− 6	22	26	27	43	71	64	80
Crowley silt loam......	8.1	9	14	2	− 3	7	13	0	46	33	18	42
Average for type....	8.1	0	7	14	− 1	6	9	9	32	42	27	42

TABLE III.—*Percentage increase in growth attributable in the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
ARKANSAS—continued.												
Prairie County—Cont'd.	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Morse clay	8.8	−9	8	1	2	11	6	0	6	−7	6	22
Morse clay	10.8	4	−3	2	−7	2	6	−3	2	4	4	9
Morse clay	11.1	5	13	−3	4	3	9	−11	−7	−1	5	4
Average for type	10.2	0	6	0	0	5	7	−5	0	−1	5	12
Acadia silt loam	11.2	0	4	29	11	25	24	27	12	33	46	27
Acadia silt loam	7.3	1	7	10	12	1	10	15	14	37	7	16
Acadia silt loam	7.4	22	20	29	31	18	22	41	23	48	31	38
Acadia silt loam	9.0	0	11	6	11	31	26	18	−11	41	32	21
Average for type	8.7	6	11	19	16	19	21	25	10	40	29	26
Waverly silt loam	6.5	15	20	27	27	15	31	38	61	55	38	54
Waverly silt loam	7.8	−7	9	−7	−3	−4	4	−3	37	40	18	41
Waverly silt loam	5.0	28	20	18	23	22	29	28	104	150	10	132
Average for type	6.4	12	16	13	16	11	21	21	67	82	22	76
Average for area	8.3	5	10	12	8	11	15	14	26	40	21	36
TEXAS.												
San Marcos area:												
Blanco loam	8.7	17	21	19	21	23	10	33	20	21	28	37
Crawford silt clay	9.2	20	21	31	20	40	29	22	20	42	40	52
Crawford silt clay	9.2	−7	2	19	−1	8	19	23	4	31	14	34
Crawford silt clay	8.8	13	25	30	18	29	30	42	24	46	56	11
Average for type	9.1	9	16	27	12	26	26	29	16	40	37	32
Houston black clay	7.9	8	8	21	8	23	9	30	15	21	30	42
Houston black clay	8.9	0	4	15	17	4	9	17	5	23	8	23
Houston black clay	7.0	20	21	31	25	33	35	35	17	42	10	38
Houston black clay	8.1	−4	−5	21	5	12	21	19	6	26	25	32
Average for type	8.0	6	7	22	14	18	19	25	11	28	18	34
Average for area	8.5	8	12	23	14	22	20	28	14	32	26	34
Rusk County:												
Caddo fine sandy loam	8.2	6	2	53	5	51	53	47	7	47	61	57
Caddo fine sandy loam	8.1	12	11	40	15	43	35	34	17	36	62	40
Average for type	8.2	9	7	47	10	47	44	40	12	42	62	49
Norfolk fine sand	8.5	14	16	41	16	29	54	49	21	55	86	48
Norfolk fine sand	7.8	−4	8	21	6	17	28	28	3	60	103	69
Norfolk fine sand	8.6	5	6	19	−3	21	36	36	10	26	61	37
Average for type	8.3	5	10	27	6	22	39	38	11	47	83	51
Norfolk fine sandy loam	7.5	20	28	38	41	42	62	65	21	64	105	62
Norfolk fine sandy loam	6.1	31	31	48	48	52	56	48	40	41	48	80
Average for type	6.8	26	30	43	45	47	59	57	31	53	76	71
Orangeburg fine sandy loam	9.2	−12	−6	14	−9	−6	14	36	13	39	68	53
Orangeburg fine sandy loam	9.2	0	2	34	−1	26	26	26	12	37	37	66
Orangeburg fine sand	7.5	−7	20	31	24	27	39	40	8	60	80	68
Susquehanna fine sandy loam	7.0	−3	0	9	−3	3	3	9	−11	26	29	36
Average for area	8.0	6	11	32	13	28	37	38	13	45	67	54

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
TEXAS—continued.												
Miscellaneous:												
Galveston clay, Galveston	*Grams.* 11.2	*P. ct.* −14	*P. ct.* −12	*P. ct.* 3	*P. ct.* −23	*P. ct.* − 9	*P. ct.* 4	*P. ct.* −20	*P. ct.* − 2	*P. ct.* − 8	*P. ct.* 4	*P. ct.* 31
Houston black clay loam, San Antonio	5.8	8	1	− 3	14	12	35	10	11	19	19	− 7
Orangeburg clay, Maroney's farm	8.6	− 3	1	17	− 3	12	7	14	4	5	29	5
Orangeburg fine sandy loam, Crockett	8.3	.....	.....	67	17	60	67	92	24	93	19	58
Orangeburg fine sandy loam, Palestine	9.8	.....	.....	30	− 7	37	31	21	7	32	−14	40
Orangeburg fine sandy loam, Nagadoches	8.8	1	6	31	10	31	43	24	16	24	56	15
Orangeburg fine sandy loam, Palestine	11.4	− 7	− 4	11	− 8	10	14	14	−15	9	37	43
IOWA.												
Miscellaneous:												
Wisconsin drift (good)	9.6	−10	15	30	−13	34	42	52	− 5	....	47	.....
Wisconsin drift (poor)	7.7	19	34	53	30	49	79	82	17	....	86	.....
Iowan drift	9.0	16	25	28	25	47	27	57	36	....	69	.....
Missouri loess	11.6	0	2	15	.....	.....	.....	.....	.....	....	5	.....
South Iowan loess	5.4	.....	.....	.....	35	32	39	41	17	....	−17	47
Kansan till	5.9	7	15	48	12	57	83	73	6	42	24	.....
ILLINOIS.												
Marion silt loam	7.7	−13	− 8	− 3	−11	− 4	9	− 8	−13	− 4	48	−12
Red silt loam	7.0	3	8	19	8	17	24	22	16	38	26	45
NEW JERSEY.												
Miscellaneous:												
Norfolk sandy loam, Woodbine	6.0	12	5	20	− 2	16	34	20	2	17	25	14
Norfolk fine sandy loam, Woodbine	6.5	1	1	9	9	22	35	32	7	31	28	42
CONNECTICUT.												
Connecticut Valley area: Hartford sandy loam	8.2	.....	.....	18	3	− 6	18	3	10	29	14	58
MARYLAND.												
Miscellaneous:												
Leonardtown loam (good)	8.3	16	7	47	.....	41	47	46	10	....	17	.....
Leonardtown loam (poor)	6.5	− 7	15	8	.....	0	12	22	1	....	24	89
Muck, peat, and swamp soils:												
Illinois	9.4	16	49	4	39	14	40	25	7	33	45	51
Iowa	15.0	24	26	21	11	− 4	15	20	−14	....	64	.....
Wisconsin, Portage County	7.2	42	25	21	51	39	39	47	23	41	51	16
Indiana, Newton County	4.4	−25	61	14	66	− 7	41	100	14	70	40	18
Virginia, Portsmouth	3.2	53	112	69	69	84	75	69	75	97	47	72
Average for type	7.8	22	55	26	47	25	42	52	21	60	49	39

COMPARATIVE EFFICIENCY OF SALTS USED SEPARATELY AND IN COMBINATION.

Table IV, which follows, is primarily for the purpose of showing the wide variation in the aggregate effect of the three fertilizer ingredients when used separately as compared with their efficiency when used together. This table gives the percentage increase or decrease in growth (the latter indicated by the minus sign) produced by acid phosphate, sulphate of potash, and nitrate of soda used separately; the aggregate increase attributable to these three ingredients; the increase when the three ingredients were combined and the difference between the aggregate and that observed when the same ingredients were used in combination. All soils having complete data for these observations are included, the total number being 190, and the data are arranged in a descending series, beginning with the greatest difference in favor of the sum of the ingredients, until the difference becomes zero, after which the series is ascending and the differences are in favor of the combination. A wide variation is shown in the last column, the difference ranging from a maximum of 165 per cent in favor of the sum of the ingredients to zero and then increasing to a maximum of 72 per cent at the other extreme in favor of the combination.

Of the total number of comparisons (190) there are 71 soils in which the efficiency of the combination exceeded the aggregate of the separate ingredients, 117 soils in which the aggregate of the individual effects exceeds that of the combination, and 2 soils in which the aggregate effect of the single ingredients exactly equals the increase in growth when those ingredients were used in combination. The number of soils that show very wide differences in respect to the aggregate efficiency of the ingredients as compared with the effect when the same ingredients are combined is small, the number increasing greatly as the lesser differences are approached. For example, 60 soils show differences of 9 per cent or less, while for 115 soils the difference is within the limit of 19 per cent. Within this limit of 19 per cent there are 51 soils in which the difference is in favor of the combination and 62 in which it is in favor of the aggregate increase for the same ingredients used separately. (See Table V following.) As a result of averages within these limits, acid phosphate gives an increase of 0.64 per cent, sulphate of potash 6.68 per cent, and nitrate of soda 19 per cent, or a total of 26.32 per cent, as compared with 24.5 per cent as a mean effect of the same ingredients used in combination on the same soils. Within these limits, which includes 60 per cent of the soils, the average efficiency of the ingredients as measured by the growth of the plants is nearly the same whether used separately or in combination. It therefore appears that each ingredient has performed special functions which differ from and are independent of those performed by the others, whether the ingredients are applied separately or in combination.

Of the soils in which the effect of the ingredients in combination differs from the aggregate effect of the same ingredients used separately by 20 per cent or more, 55 are in favor of the ingredients used separately and 20 in favor of their combination. Within the former group of soils there are 15 instances in which the aggregate increase of the ingredients when used separately is more than three times as great as when the same ingredients were used in combination, and 12 instances where the aggregate is less than three times but more than two times as great as when used in combination. Within this group, therefore, the function of the several ingredients is to a considerable degree identical, at least so far as they effect an increase in the growth of plants, and one may be substituted for another to a considerable extent.

Of the soils in which the efficiency of the combination exceeds that of the same ingredients used separately by 20 per cent or more there are only 20. In this group the function of each ingredient is not only different from that of the others, but each is dependent upon the presence of others in order that it may have the greatest effect.

There is no apparent relation either by soil type or locality with this grouping of the soils; neither do the soils of one group appear to be particularly more responsive to the complete fertilizer than those of another. Of 190 observations on each, the individual ingredients give negative results as follows: Acid prosphate 66 times, sulphate of potash 31 times, and nitrate of soda 22 times. The combination of all three ingredients gives a negative result only 9 times, while the aggregate effect of the individual ingredients becomes negative 21 times.

Table V shows the average increase produced by each ingredient, the aggregate increase, and the actual increase when the ingredients were combined for soils in which the aggregate increase from individual ingredients differs within certain limits from that obtained when the same ingredients were combined.

There are ten soils in which each of the three ingredients when used separately gave a greater increase in growth than when all were combined and ten others in which two of the three each equaled or exceeded the gain produced by the three combined. (See Tables VI and VII.) These soils are not confined to particular localities or types, neither are they associated with high or low degree of natural fertility, as may be seen by the wide range in weight of plants on the untreated soils.

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, as compared with the observed increase when a mixture of the three fertilizers was applied.*

[Results arranged in descending series, beginning with the greatest actual difference in favor of the sum of the ingredients.]

State.	Locality.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Virginia	Portsmouth	Peat	3.2	53	112	69	234	69	165
North Carolina.	Edgecombe	Norfolk fine sandy loam.	4.8	44	42	63	149	56	93
Mississippi	Pontotoc County	Lufkin silt loam	5.4	41	44	52	137	50	87
Louisiana	Caddo Parish	Caddo fine sandy loam.	4.4	18	18	86	122	36	86
Texas	Rusk County	Norfolk fine sandy loam.	6.1	31	31	48	110	48	62
Louisiana	Caddo Parish	Norfolk fine sand	3.7	– 3	51	62	110	51	59
North Carolina.	Iredell test farm.	Cecil clay	4.5	86	34	42	162	105	57
Virginia	Louisa County	Cecil loam	4.6	36	47	75	158	102	56
Louisiana	Caddo Parish	Miller fine sand	7.3	21	26	10	57	1	56
North Carolina.	Pinehurst	Portsmouth sand	4.8	42	26	42	110	56	54
Missouri	Crawford County.	Clarksville silt loam.	6.6	26	15	17	58	7	51
Iowa	Ames	Peat	15.0	24	26	21	71	20	51
Texas	San Marcos	Crawford silt clay	9.2	20	21	31	72	22	50
North Carolina.	New Hanover County.	Norfolk sand	4.1	37	41	122	200	151	49
North Carolina.	Blantyre	Porter's sandy loam.	4.5	4	44	20	68	24	44
Illinois	Manito	Muck	9.4	16	49	4	69	25	44
Louisiana	Caddo Parish	Miller fine sand	5.8	12	12	38	62	19	43
Louisiana	Caddo Parish	Caddo fine sandy loam.	6.0	6	17	26	49	8	41
Wisconsin		Muck	7.2	42	25	21	88	47	41
Indiana	Newton County	Marshall loam	7.6	17	22	17	56	16	40
Mississippi	Montgomery County.	Orangeburg fine sandy loam.	7.5	24	20	43	87	48	39
Florida	Escambia County.	Norfolk fine sandy loam.	3.3	24	36	27	87	48	39
Arkansas	Prairie County	Waverly silt loam.	5.0	28	20	18	66	28	38
Texas	San Marcos area	Houston black clay.	7.0	20	21	31	72	35	37
South Carolina.	York County	Cecil sandy loam	7.0	40	3	28	71	34	37
New York	Geneseo	Dunkirk clay loam.	8.9	16	29	20	65	28	37
Florida	Escambia County.	Norfolk sand	5.9	5	32	45	82	46	36
Florida	Escambia County.	Norfolk sand	5.4	16	18	13	47	11	36
New York	Genesee County	Dunkirk clay loam.	10.2	11	11	18	40	5	35
Florida	Escambia County.	Norfolk sand	7.2	4	19	33	56	22	34
Georgia	Waycross area	Norfolk fine sandy loam.	7.5	17	28	60	105	73	32
North Carolina.	Raleigh	Cecil sandy loam	4.1	20	31	30	81	49	32
Mississippi	Montgomery County.	Lintonia loam	8.5	7	17	29	53	22	31
Arkansas	Prairie County	Acadia silt loam	7.4	22	20	29	71	41	30
Indiana	Newton County	Marshall fine sandy loam.	6.3	5	12	9	26	– 4	30
Georgia	Waycross area	Norfolk sand	5.6	– 4	30	61	87	57	30
Texas	Rusk County	Caddo fine sandy loam.	8.1	12	11	40	63	34	29
Georgia	Waycross area	Norfolk fine sandy loam.	3.9	11	29	74	114	86	28
North Carolina.	Tarboro	Norfolk fine sandy loam.	5.3	25	22	42	89	63	26
Texas	San Marcos area	Crawford silt clay	8.8	13	25	30	68	42	26
Arkansas	Prairie County	Crowley silt loam	7.0	0	10	43	53	27	26
Arkansas	Prairie County	Morse clay	11.1	5	13	–3	15	–11	26
Louisiana	Caddo Parish	Norfolk fine sand	5.4	21	19	41	81	56	25
Arkansas	Prairie County	Crowley silt loam	8.1	9	14	2	25	0	25
Iowa	Ames	Wisconsin drift (poor).	7.7	19	34	53	106	82	24
Arkansas	Prairie County	Waverly silt loam.	6.5	15	20	27	62	38	24
Texas	San Marcos	Blanco loam	8.7	17	21	19	57	33	24
Maryland	Leonardtown	Leonardtown loam (good).	8.3	16	7	47	70	46	24
Georgia	Waycross area	Portsmouth fine sand.	5.2	6	21	73	100	77	23
Alabama	Lee County	Norfolk sandy loam.	7.7	12	19	55	86	63	23
Louisiana	Caddo Parish	Caddo fine sandy loam.	5.0	–10	4	33	27	4	23

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Texas	Rusk County	Norfolk fine sand.	8.5	14	16	41	71	49	22
Alabama	Ford's farm	Orangeburg clay	9.1	22	24	42	88	67	21
Texas	Rusk County	Norfolk fine sandy loam.	7.5	20	28	38	86	65	21
Indiana	Tippecanoe County.	Miami silt loam	5.6	30	21	28	79	58	21
Louisiana	Caddo Parish	Norfolk fine sandy loam.	5.6	− 3	20	35	52	33	19
North Carolina	Biltmore farm	Porters clay	12.4	11	15	18	44	25	19
North Carolina	Wake County	Tobacco soil	4.7	9	11	28	48	30	18
Louisiana	Caddo Parish	Orangeburg fine sand.	7.4	8	10	21	39	21	18
Ohio	Westerville area	Miami clay loam	6.1	11	5	15	31	13	18
Mississippi	Pontotoc County.	Orangeburg sandy loam.	7.6	17	− 2	28	43	26	17
New Jersey	Woodbine	Norfolk sandy loam.	6.0	12	5	20	37	20	17
Missouri	Scotland County.	Shelby silt loam	9.6	7	24	14	45	28	17
Pennsylvania	Montgomery County.	Lansdale silt loam	9.9	0	23	1	24	7	17
Georgia	Waycross	Norfolk fine sand.	6.0	5	8	53	66	50	16
Wisconsin	Portage County	Miami sand	6.0	7	15	33	55	39	16
Mississippi	Pontotoc County	Lufkin clay	6.4	8	8	28	44	28	16
Mississippi	Montgomery County.	Memphis silt loam.	7.0	7	9	14	30	14	16
Pennsylvania	Montgomery County.	Penn silt loam	12.3	8	12	8	28	13	15
New York	Binghamton area.	Dunkirk gravelly sandy loam.	6.6	4	1	11	16	1	15
Louisiana	Caddo Parish	Norfolk fine sandy loam.	9.6	− 8	9	13	14	− 1	15
Texas	Rusk County	Caddo fine sandy loam.	8.2	6	2	53	61	47	14
Texas	Nagadoches	Orangeburg fine sandy loam.	8.8	1	6	31	38	24	14
New York		Volusia silt loam	6.6	4	22	10	36	23	13
Iowa		Iowan drift	9.0	16	25	28	69	57	12
New York		Volusia silt loam	4.8	− 2	15	34	47	35	12
Wisconsin	Portage County	Marshall sand	8.4	7	9	31	47	35	12
Virginia	Louisa County	Cecil sandy loam	7.2	24	5	13	42	30	12
Arkansas	Prairie County	Calhoun clay	8.3	12	12	14	38	26	12
New York	Binghamton area.	Dunkirk gravelly loam.	10.6	9	9	1	19	7	12
Georgia	Waycross area	Norfolk fine sandy loam.	7.9	1	5	29	35	24	11
Florida	Escambia County	Norfolk fine sandy loam.	8.4	− 7	14	15	22	11	11
New York	Tompkins County	Dunkirk clay loam.	9.0	0	9	13	22	11	11
Louisiana	Caddo Parish	Norfolk fine sandy loam.	8.7	4	9	7	20	9	11
Wisconsin	Portage County	Miami sandy loam	9.0	4	8	2	14	3	11
Georgia	Waycross area	Norfolk sandy loam.	5.0	0	16	20	36	25	11
North Carolina.	New Hanover County.	Portsmouth fine sand.	3.0	13	30	77	120	110	10
North Carolina.	Statesville	Iredell clay loam	5.2	7	21	16	44	34	10
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	0	2	34	36	26	10
New York		Volusia silt loam	5.4	2	15	13	30	20	10
Louisiana	Caddo Parish	Norfolk fine sand	5.3	15	21	32	68	59	9
South Carolina.	Cherokee County.	Iredell clay loam	9.1	− 3	7	32	36	27	9
Alabama	Lee County	Cecil sandy loam	8.6	1	9	14	24	15	9
Ohio	Strongsville	Miami clay loam		− 4	− 5	12	3	− 6	9
Illinois	Pulaski	Red silt loam	7.0	3	8	19	30	22	8
Wisconsin	Portage County	Miami stony sand.	9.9	6	13	11	30	22	8
Florida	Escambia County.	Portsmouth sand	8.3	2	5	12	19	11	8
South Carolina.	Cherokee County.	Cecil silt loam	6.6	2	1	52	55	48	7
Texas	San Marcos	Houston black clay	7.9	8	8	21	37	30	7
Alabama	King's farm	Orangeburg clay	10.3	3	6	17	26	19	7
South Carolina.	York County	Iredell clay loam	7.7	0	6	19	25	18	7
Wisconsin	Portage County	Marshall gravelly loam.	11.0	− 1	− 2	14	11	4	7
Alabama	Lee County	Norfolk coarse sand.	5.3	− 7	15	48	56	50	6
Arkansas	Prairie County	Acadia silt loam	11.2	0	4	29	33	27	6

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Arkansas	Prairie County	Morse clay	10.8	4	−3	2	3	−3	6
Georgia	Waycross area	Norfolk sand	6.1	−2	−5	36	29	24	5
Texas	Rusk County	Orangeburg fine sand.	7.5	−7	20	31	44	40	4
Virginia	Hanover County	Norfolk sandy loam.	7.5	3	11	20	34	30	4
Georgia	Waycross area	Norfolk fine sand	6.1	7	15	55	77	74	3
Arkansas	Prairie County	Acadia silt loam	7.3	1	7	10	18	15	3
Pennsylvania	Montgomery County.	Hagerstown loam.	10.3	13	−2	1	12	9	3
Tennessee	Henderson County.	Lexington silt loam.	7.5	1	1	36	38	36	2
North Carolina	Asheville	Porters clay	5.8	−6	−2	29	21	19	2
Texas	San Marcos area	Houston black clay	8.9	0	4	15	19	17	2
Missouri	Crawford County.	Clarksville stony loam.	14.6	4	3	−2	5	3	2
Texas	Maroney's farm	Orangeburg clay	8.6	−3	1	17	15	14	1
New York	Tompkins County	Dunkirk loam	8.4	−4	2	15	13	12	1
Indiana	Tippecanoe County.	Marshall loam	7.5	−3	2	7	6	6	0
Arkansas	Prairie County	Morse clay	8.8	−9	8	1	0	0	0
Arkansas	Prairie County	Crowley silt loam	10.1	−1	3	0	2	3	1
Indiana	Tippecanoe County.	Marshall silt loam.	7.2	4	1	6	11	12	1
Arkansas	Prairie County	Acadia silt loam	9.0	0	11	6	17	18	1
North Carolina.	New Hanover County.	Norfolk fine sandy loam.	7.3	3	3	22	28	29	1
New York	Tompkins County	Dunkirk clay loam	4.5	−18	4	55	41	42	1
Ohio	Westerville area	Miami loam	8.6	−8	3	−2	−7	−5	2
Arkansas	Prairie County	Waverly silt loam.	7.8	−7	9	−7	−5	−3	2
South Carolina.	Cherokee County	Cecil fine sandy loam.	5.9	−3	7	46	50	52	2
North Carolina.	Statesville	Cecil clay (good)	8.8	0	−2	−4	−6	−4	2
Texas	Galveston	Galveston clay	11.2	−14	−12	3	−23	−20	3
Texas	Rusk County	Susquehanna fine sandy loam.	7.0	−3	0	9	6	9	3
Texas	Rusk County	Norfolk fine sand	7.8	−4	8	21	25	28	3
Kentucky	McCracken County.	Memphis silt loam.	5.0	−3	3	39	39	42	3
Alabama	Lee County	Norfolk sand	6.8	9	10	40	59	62	3
Iowa	Leon	Kansan till	5.9	7	15	48	70	73	3
Louisiana	Caddo Parish	Caddo fine sandy loam.	8.8	−7	5	7	5	9	4
Texas	San Antonio	Houston black clay loam.	5.8	8	1	−3	6	10	4
North Carolina.	Statesville	Cecil clay (poor)	8.8	−1	1	0	0	5	5
New York	Tompkins County.	Miami stony loam.	9.6	4	1	1	6	11	5
Georgia	Waycross	Norfolk sandy loam.	6.5	11	15	54	80	85	5
Arkansas	Prairie County	Crowley silt loam	7.1	−8	0	9	1	7	6
Maryland	Leonardtown	Leonardtown loam (poor).	6.5	−7	15	8	16	22	6
Texas	Rusk County	Norfolk fine sand	8.6	5	6	19	30	36	6
Alabama	Rawles's farm	Orangeburg sandy loam.	8.1	6	−5	4	5	12	7
Texas	San Marcos area	Houston black clay	8.1	−4	−5	21	12	19	7
Alabama	Lee County	Norfolk sand	4.7	−1	−1	30	28	35	7
South Carolina.	Cherokee County	Cecil sandy loam	6.9	−12	28	35	51	58	7
Mississippi	Montgomery County.	Memphis silt loam.	8.6	−13	6	12	5	13	8
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	6.5	3	3	0	6	15	9
Texas	San Marcos area	Crawford silt clay.	9.2	−7	2	19	14	23	9
South Carolina.	Cherokee County.	Cecil clay	7.4	−4	−6	36	26	35	9
Virginia	Pocahontas field	Cecil clay	11.7	−3	4	−3	−2	9	11
Mississippi	Pontotoc County.	Monroe silt loam	8.0	−4	−6	13	3	14	11
New York	Binghamton area.	Wabash loam	10.6	−1	11	5	15	26	11
Missouri	Crawford County.	Wabash silt loam	7.6	−11	1	−3	−13	−1	12
Georgia	Waycross	Norfolk sand	5.5	−9	24	45	60	72	12
South Carolina.	St. Matthews	Orangeburg sandy loam.	11.8	0	−2	15	13	26	13
Texas	Palestine	Orangeburg fine sandy loam.	11.4	−7	−4	11	0	14	14

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, etc.*—Continued.

State.	Area.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Pennsylvania	Montgomery County.	Chester loam	7.8	0	9	4	13	27	14
North Carolina.	Union County	Silt loam	4.6	− 4	0	32	28	42	14
Alabama	Lee County	Norfolk sandy loam.	6.1	−14	4	42	32	46	14
North Carolina.	New Hanover County.	Norfolk fine sand	6.4	3	9	37	49	63	14
Ohio	Westerville area	Miami black clay loam.	8.3	−11	6	− 2	− 7	8	15
Florida	Escambia County	Norfolk fine sandy loam.	5.5	10	12	− 5	17	32	15
Illinois		Marion silt loam	7.7	−13	− 8	− 3	−24	− 8	16
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	5.0	0	6	10	16	32	16
Wisconsin	Portage County	Portage silt loam	8.7	2	−16	− 2	−16	1	17
Alabama	Lee County	Norfolk coarse sand.	6.4	−12	0	20	8	25	17
Iowa		Wisconsin drift (good).	9.6	−10	15	30	35	52	17
Georgia	Waycross	Portsmouth fine sand.	5.5	2	18	33	53	71	18
Mississippi	Montgomery County.	Memphis silt loam.	10.6	−13	− 3	− 2	−18	1	19
Indiana	Newton County	Clyde fine sand	12.6	−21	− 2	−14	−37	−17	20
Mississippi	Montgomery County.	Memphis silt loam.	9.5	−16	− 9	0	−25	− 5	20
New Jersey	Woodbine	Norfolk fine sandy loam.	6.5	1	1	9	11	32	21
Georgia	Waycross	Norfolk sandy loam.	7.0	− 7	14	36	43	64	21
Virginia	Hanover County	Wickham sandy loam.	7.5	− 3	5	11	13	36	23
Alabama	Marion	Orangeburg sandy loam.	4.8	14	7	25	46	69	23
Georgia	Waycross	Portsmouth fine sand.	5.2	1	15	50	66	90	24
North Carolina.	Chowan County	Portsmouth silt loam.	4.5	2	19	14	35	62	27
Wisconsin	Portage County	Portage silt loam	10.0	−11	− 9	− 6	−26	3	29
Mississippi	Montgomery County.	Memphis silt loam.	10.2	− 3	− 2	−15	−20	12	32
Alabama	Lee County	Cecil sandy loam	5.6	−11	− 7	29	11	43	32
Mississippi	Pontotoc County.	Orangeburg clay	6.6	− 9	3	18	12	45	33
Georgia	Waycross	Norfolk fine sand	7.4	− 9	− 8	− 3	−20	14	34
Mississippi	Montgomery County.	Memphis silt loam.	11.2	−10	− 7	−11	−28	8	36
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	−12	− 6	14	− 4	36	40
Louisiana	Caddo Parish	Norfolk fine sandy loam.	7.9	1	− 5	−10	−14	35	49
Indiana	Newton County	Muck	4.4	−25	61	14	50	100	50
South Carolina.	York County	Cecil sand	3.9	−15	− 8	26	3	54	51
Louisiana	Caddo Parish	Orangeburg fine sand.	5.0	−22	−10	−10	−42	28	70
Rhode Island	Kingston	Miami silt loam	3.6	− 8	−19	−14	−41	31	72

Table V.—*Average percentage increase in growth attributable to P, K, and N and the aggregate increase of the same salts used individually as compared with the actual increase when the same salts were used together, averages being for the soils in which the difference between the aggregate and actual increase is within limits indicated in the first column.*

Range of difference.	Number of soils.	Green weight of plants.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to mixture of PKN.	Difference.
			P.	K.	N.			
Per cent.		*Grams.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
60+	5	4.8	37	49	64	150	52	98
50–59	8	7.0	31	31	38	100	46	54
40–49	7	6.4	19	30	35	84	41	43
30–39	16	6.7	16	22	31	69	34	35
20–29	19	7.3	13	19	38	70	46	24
10–19	35	7.6	6	12	22	40	26	14
0–9	28	8.3	1	5	22	28	23	5
9–0	32	7.6	− 2	4	17	19	23	− 4
19–10	20	7.9	− 5	4	14	13	28	−15
29–20	9	7.5	− 4	4	14	14	37	−23
39–30	5	8.2	− 8	−5	4	−9	24	−33
49–40	2	8.6	− 6	−5	2	−9	36	−45
50+	4	4.2	−18	6	4	−8	53	−61

Table VI.—*Ten soils in which percentage increase attributable to each ingredient is greater than that produced when all are combined.*

State.	Locality.	Soil type.	Weight of plants grown on untreated soil.	Increase attributable to—			Sum of PKN.	Increase attributable to mixture of PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Louisiana	Caddo Parish	Miller fine sand	7.3	21	26	10	57	1	56
Iowa	Ames	Peat	15.0	24	26	21	71	20	51
Missouri	Crawford County	Clarksville silt loam.	6.6	26	15	17	58	7	51
Indiana	Newton County	Marshall loam	7.6	17	22	17	56	16	40
Florida	Escambia County	Norfolk sand	5.4	16	18	13	47	11	36
New York	Geneseo	Dunkirk clay loam.	10.2	11	11	18	40	5	35
Indiana	Newton County	Marshall fine sandy loam.	6.3	5	12	9	26	− 4	30
Arkansas	Prairie County	Morse clay	11.1	5	13	−3	15	−11	26
Arkansas	Prairie County	Crowley silt loam.	8.1	9	14	2	25	0	25
New York	Binghamton area.	Dunkirk gravelly sandy loam.	6.6	4	1	11	16	1	15
	Average		8.4	14	16	11	41	5	36

TABLE VII.—*Ten soils in which two of the three ingredients each produced a greater increase than when all three were combined.*

State.	Locality.	Soil type.	Weight of plants grown on untreated soil.	Increase attributable to—			Sum of PKN.	Increase attributable to mixture of PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Virginia	Portsmouth	Peat	3.2	53	112	69	234	69	165
Louisiana	Caddo Parish	Norfolk fine sand	3.7	3	51	62	110	51	59
Louisiana	Caddo Parish	Caddo fine sandy loam.	6.0	6	17	26	49	8	41
Louisiana	Caddo Parish	Caddo fine sandy loam.	5.0	−10	4	33	27	4	23
Louisiana	Caddo Parish	Norfolk fine sandy loam.	9.6	− 8	9	13	14	− 1	15
New York	Binghamton area	Dunkirk gravelly loam.	10.6	9	9	1	19	7	12
Florida	Escambia County	Norfolk fine sandy loam.	8.4	− 7	14	15	22	11	11
Wisconsin	Portage County	Miami sandy loam.	9.0	4	8	2	14	3	11
Arkansas	Prairie County	Morse clay	10.8	4	− 3	2	3	− 3	6
Missouri	Crawford County	Clarksville stony loam.	14.6	4	3	− 2	5	3	2
	Average		8.1	5	23	22	50	15	35

NITRATE OF SODA ALONE AND WITH OTHER SALTS.

A study of Table IV shows that in 66 per cent of the instances nitrate of soda when used alone has produced an increase of growth which equals or exceeds that produced by either sulphate of potash or acid phosphate.

A tabulation of the data for nitrate of soda and of combinations in which it enters shows that the nitrate of soda has a marked beneficial effect on the majority of soils which on an average is not increased by the addition of acid phosphate. A comparison of the nitrate with the nitrate-phosphate column shows a difference in favor of the former in slightly more than half of the comparisons. The average of these two columns shows a difference of less than one-tenth of 1 per cent.

Nitrate of soda when supplemented with sulphate of potash gives an increase in growth which in 74 per cent of the instances equals or exceeds that produced by nitrate of soda alone, the average result being 8.5 per cent in favor of the combination. When this nitrogen-potash combination is still further supplemented by acid phosphate there is on an average no additional increase in growth. In fact the instances in which the nitrogen-potash combination equals or exceeds that of the complete fertilizer are slightly in the majority. The tabulation above mentioned is not published, but the same facts may be gathered by careful study of those columns in Table III, which give the results for nitrogen and all combinations into which it enters.

SULPHATE OF POTASH ALONE AND WITH OTHER SALTS.

Sulphate of potash when supplemented by acid phosphate produced an increase in growth, which in 50 per cent of the soils exceeded that produced by potash alone, the average increase being one-tenth of 1 per cent in favor of the combination. When the potash salt is combined with nitrate of soda there is a marked increase in growth over that produced by potash alone, which, on the average, is not further increased by the addition of acid phosphate. In 86 per cent of the soils the effect of potash combined with nitrogen has equaled or exceeded the effect of potash alone. These facts are brought out by a study of the columns in Table III, in which potash occurs, omitting all soils for which the data for this salt and all its combinations are incomplete.

ACID PHOSPHATE ALONE AND WITH OTHER SALTS.

Referring to Table IV, the striking fact is the large number of instances in which acid phosphate gives a small or negative effect. The efficiency is quite regularly increased (see all columns of Table III in which phosphate enters) as each fertilizer salt is added, the exceptions to this being mostly for those soils in which the efficiency of the complete fertilizer as a whole becomes quite small or is negative.

In the life and economy of the plant, phosphates are generally recognized to be instrumental chiefly in the production of seed or fruit, and have a tendency to hasten maturity, and may influence the color and quality of the fruit. It is also known that plants do not absorb extraneous phosphates during the very early stages of growth. From the standpoint of the requirements of the plant, no response would be expected from the phosphates, and it is, therefore, not strange that in many instances a small or negative effect has resulted from their application. It should be borne in mind, however, that this is not a study of the plant's requirements, but a study of the fertility of the soil as affected by fertilizers and that the plants have been used merely as the indicator of the degree to which fertility has been affected by the various applications. It is now contended that aside from the direct action that various salts have on the growth and economy of the plant, they may also act directly on the soil, thereby increasing its fertility in a way not fully understood.

An inspection of the tables will show that while small and negative effects have often resulted from the phosphate, there are 55 soils in which the increase in growth attributable to this salt when used alone has ranged from 10 to 50 per cent and in two instances even more.

LIME ALONE AND WITH FERTILIZER SALTS.

Table VIII shows the increase in growth attributable to lime, to a complete fertilizer with and without lime, to manure, and to cowpea vines with lime. The soils are arranged in a descending series as determined by the efficiency of the complete fertilizer without lime. Lime alone shows quite a marked effect in the majority of the soils, and while its efficiency corresponds in a general way with that of a complete fertilizer there are numerous exceptions to this. The lime may have little or no effect where the fertilizer is markedly beneficial. For example, in the upper portion of the table where the figures for the complete fertilizer range from 50 to 75 per cent increase in growth there are 8 soils on which lime gives less than 10 per cent increase, while in the lower portion of the table where the complete fertilizer does not exceed 11 per cent there are 7 instances where the increase in growth attributable to lime exceeds 30 per cent. As a rule, the efficiency of the complete fertilizer has been appreciably increased by the addition of lime. There seems to be little evidence in support of the contention sometimes made that the benefits due to lime are attributable to its favorable action on nitrification.

A study of Table IX, which summarizes the results of Table VIII and all data for the same soils in Table III—i. e., gives the mean percentage increase in growth attributable to the several fertilizer salts and combinations for groups of soils in which the efficiency of a complete fertilizer falls within certain limits as given in the second column—shows that as the efficiency of a complete fertilizer declines there is a corresponding decline in the effect of practically all ingredients and combinations. This is equally as true for manure or for potash and phosphate as it is for nitrate of soda and lime, so that the parallel decline in the lime and nitrate columns in the table loses significance. Of the soils in Table VIII, where the efficiency of a complete fertilizer is not less than 25 nor more than 75 per cent, there are 17 in which the efficiency of lime exceeds 35 per cent and 31 in which it is 10 per cent or less. As a result of averages of these two groups of soils, we get the following results: Seventeen soils (lime giving increase of 35 per cent or more) average efficiency, lime 63, N 35, NKP 49; 31 soils (lime giving increase of 10 per cent or less) lime 4, N 24, NKP 40. The effect of nitrogen is obtained from Table III.

The difference in the efficiency of lime is here very marked, dropping from an average of 63 per cent for the 17 soils to only 4 per cent for the 31 soils. The relative decline in the effect of nitrate of soda and the complete fertilizer, however, is small, being from 35 to 24 for the former and 49 to 40 for the latter.

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, a complete fertilizer with lime, a complete fertilizer, manure, and cowpea vines with lime.*

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
North Carolina	New Hanover County.	Norfolk sand	4.1	66	154	151	254	144
North Carolina	New Hanover County.	Portsmouth fine sand.	3.0	70	173	110	130	230
North Carolina	Iredell test farm	Cecil clay	4.5	45	105	105	90	......
Virginia	Louisa County	Cecil loam	4.6	71	153	102	63	158
Indiana	Newton County	Peat	4.4	14	70	100	40	18
Georgia	Waycross area	Portsmouth fine sand.	5.2	92	153	90	219	175
Georgia	Waycross area	Norfolk fine sandy loam.	3.9	64	105	86	150	176
Georgia	Waycross area	Norfolk sandy loam	6.5	35	100	85	109	109
Iowa	Ames	Wisconsin drift (poor).	7.7	17	....	82	86	......
Georgia	Waycross area	Portsmouth fine sand.	5.2	29	117	77	150	148
Georgia	Waycross area	Norfolk fine sand	6.1	34	84	74	102	107
Georgia	Waycross area	Norfolk fine sandy loam.	7.5	40	89	73	113	113
Iowa	Leon	Kansan till	5.9	6	42	73	24	......
Georgia	Waycross area	Norfolk sand	5.5	64	109	72	124	118
Georgia	Waycross area	Portsmouth fine sand.	5.5	20	75	71	64	109
Alabama	Marion	Orangeburg sandy loam.	4.8	12	69	69	37	60
Virginia	Portsmouth	Peat	3.2	75	97	69	47	72
Alabama	Marion	Orangeburg clay	9.1	20	55	67	49	35
Texas	Rusk County	Norfolk fine sandy loam.	7.5	21	64	65	105	62
Georgia	Waycross area	Norfolk sandy loam.	7.0	0	57	64	103	94
North Carolina	New Hanover County.	Norfolk fine sand	6.4	16	70	63	94	37
North Carolina	Tarboro	Norfolk fine sandy loam.	3.0	1	70	63	38	78
Alabama	Lee County	Norfolk sandy loam.	7.7	19	87	63	61	164
North Carolina	Chowan County	Portsmouth silt loam.	4.5	19	57	62	46	74
Alabama	Lee County	Norfolk sand	6.8	57	103	62	107	160
Louisiana	Caddo Parish	Norfolk fine sand	5.3	9	74	59	28	80
Indiana	Tippecanoe County.	Miami silt loam	5.6	17	35	58	71	30
South Carolina	Cherokee County	Cecil sandy loam	6.9	4	65	58	71	5
Georgia	Waycross area	Norfolk sand	5.6	20	121	57	114	132
Iowa	Blackhawk County.	Iowan drift	9.0	36	....	57	69	......
North Carolina	Edgecombe	Norfolk fine sandy loam.	4.8	25	77	56	66	......
North Carolina	Pinehurst	Portsmouth sand	4.8	26	46	56	41	45
Louisiana	Caddo Parish	Norfolk fine sand	5.4	39	80	56	92	98
South Carolina	York County	Cecil sand	3.9	8	51	54	90	60
South Carolina	Cherokee County	Cecil fine sandy loam.	5.9	29	68	52	88	123
Iowa	Ames	Wisconsin drift (good).	9.6	−5	....	52	47	......
Louisiana	Caddo Parish	Norfolk fine sand	3.7	41	113	51	146	195
Alabama	Lee County	Norfolk coarse sand.	5.3	5	70	50	59	101
Mississippi	Pontotoc area	Lufkin silt loam	5.4	63	56	50	37	78
Georgia	Waycross area	Norfolk fine sand	6.0	27	32	50	113	107
North Carolina	Raleigh	Cecil sandy loam	4.1	52	103	49	53	54
Texas	Rusk County	Norfolk fine sand	8.5	21	55	49	86	48
South Carolina	Cherokee County	Cecil silt loam	6.6	39	56	48	81	74
Florida	Escambia County	Norfolk fine sandy loam.	3.3	136	130	48	90	136
Mississippi	Montgomery County.	Orangeburg fine sandy loam.	7.5	24	64	48	60	60
Texas	Rusk County	Norfolk fine sandy loam.	6.1	40	41	48	48	80
Texas	Rusk County	Caddo fine sandy loam.	8.2	7	47	47	61	57
Wisconsin	Portage County	Muck	7.2	23	41	47	51	16

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Florida	Escambia County	Norfolk sand	5.9	24	55	46	94	97
Alabama	Lee County	Norfolk sandy loam.	6.1	11	64	46	42	104
Mississippi	Pontotoc County.	Orangeburg clay	6.6	−3	47	45	18	32
Alabama	Lee County	Cecil sandy loam	5.6	13	52	43	43	......
New York	Tompkins County.	Dunkirk clay loam	4.5	29	....	42	33	54
North Carolina	Union County	Silt loam	4.6	4	51	42	28	......
Kentucky	McCracken County.	Memphis silt loam	5.0	18	48	42	70	2
Texas	San Marcos area	Crawford silt clay	8.8	24	46	42	56	11
Arkansas	Prairie County	Acadia silt loam	7.4	23	48	41	31	38
Texas	Rusk County	Orangeburg fine sand.	7.5	8	60	40	80	68
Wisconsin	Portage County	Miami sand	6.0	7	43	39	80	−4
Arkansas	Prairie County	Waverly silt loam	6.5	61	55	38	38	54
Virginia	Louisa County	Wickham sandy loam.	7.5	9	35	36	31	−12
Tennessee	Henderson County.	Lexington silt loam.	7.5	5	57	36	72	17
Louisiana	Caddo Parish	Caddo fine sandy loam.	4.4	18	52	36	20	186
Texas	Rusk County	Norfolk fine sand	8.6	10	26	36	61	37
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	13	39	36	68	53
Wisconsin	Portage County	Marshall sand	8.4	11	8	35	34	3
New York	....	Volusia silt loam	4.8	15	62	35	81	......
South Carolina	Cherokee County.	Cecil clay	7.4	4	44	35	42	12
Alabama	Lee County	Norfolk sand	4.7	50	135	35	108	143
Louisiana	Caddo Parish	Norfolk fine sandy loam.	7.9	2	56	35	18	47
Texas	San Marcos area	Houston black clay.	7.0	17	42	35	10	38
North Carolina	Statesville	Iredell clay loam	5.2	−1	28	34	33	......
South Carolina	York County	Cecil sandy loam	7.0	33	41	34	76	58
Texas	Rusk County	Caddo fine sandy loam.	8.1	17	36	34	62	40
Louisiana	Caddo Parish	Norfolk fine sandy loam.	5.6	28	54	33	54	52
Texas	San Marcos area	Blanco loam	8.7	20	21	33	28	37
Florida	Escambia County.	Norfolk fine sandy loam.	5.5	45	82	32	32	85
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	5.0	0	44	32	34	96
New Jersey	Woodbine	Norfolk fine sandy loam.	6.5	7	31	32	28	42
Rhode Island	Kingston	Miami silt loam	3.6	133	111	31	39	......
Virginia	Louisa County	Cecil sandy loam	7.2	5	39	30	25	57
Virginia	Hanover County	Norfolk sandy loam	7.5	−1	47	30	44	−8
North Carolina	Wake County	Tobacco soil	4.7	11	16	30	.....	..
Texas	San Marcos area	Houston black clay.	7.9	15	21	30	30	42
North Carolina	New Hanover County.	Norfolk fine sandy loam.	7.3	8	31	29	57	34
Missouri	Scotland County	Shelby silt loam	9.6	11	28	28	69	30
New York	Geneseo	Dunkirk clay loam	8.9	19	22	28	17	28
Mississippi	Pontotoc area	Lufkin clay	6.4	6	31	28	9	48
Louisiana	Caddo Parish	Orangeburg fine sand.	5.0	12	15	28	114	124
Arkansas	Prairie County	Waverly silt loam	5.0	104	150	28	10	132
Texas	Rusk County	Norfolk fine sand	7.8	3	60	28	103	69
Pennsylvania	Montgomery County.	Chester loam	7.8	4	33	27	13	8
South Carolina	Cherokee County	Iredell clay loam	9.1	14	42	27	36	7
Arkansas	Prairie County	Crowley silt loam	7.0	43	71	27	64	80
Arkansas	Prairie County	Acadia silt loam	11.2	12	33	27	46	27
South Carolina	St. Matthews	Orangeburg sandy loam.	11.8	19	28	26	25	17
New York	Binghamton County.	Wabash loam	10.6	10	15	26	31	10
Mississippi	Pontotoc County.	Orangeburg sandy loam.	7.6	6	39	26	25	24
Arkansas	Prairie County	Calhoun clay	8.3	18	27	26	4	13
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	12	37	26	37	66
North Carolina	Biltmore	Porters clay	12.4	31	26	25	61	24

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Georgia	Waycross area	Norfolk sandy loam	5.0	−9	43	25	54	42
Alabama	Lee County	Norfolk coarse sand	6.4	22	23	25	33	41
Illinois	Manito	Muck	9.4	7	33	25	45	51
North Carolina	Blantyre	Porters sandy loam.	4.5	43	22	24	61	31
Georgia	Waycross area	Norfolk sand	6.1	34	55	24	77	65
Georgia	Waycross area	Norfolk fine sandy loam.	7.9	22	35	24	96	67
Texas	Nacogdoches	Orangeburg fine sandy loam.	8.8	16	24	24	56	15
New York		Volusia silt loam	6.6	8	15	23	77	13
Texas	San Marcos area	Crawford silt clay	9.2	4	31	23	14	34
Wisconsin	Portage County	Miami stony sand	9.9	−3	19	22	47	8
Florida	Escambia County	Norfolk sand	7.2	29	23	22	66	65
Mississippi	Montgomery County.	Lintonia loam	8.5	24	16	22	30	48
Texas	San Marcos area	Crawford silt clay	9.2	20	42	22	40	52
Illinois	Pulaski County	Red silt loam	7.0	16	38	22	26	45
Louisiana	Caddo Parish	Orangeburg fine sand.	7.4	20	28	21	15	28
New York	Ithaca	Volusia silt loam	5.4	9	32	20	51	29
New Jersey	Woodbine	Norfolk sandy loam	6.0	2	17	20	25	14
Iowa	Ames	Muck	15.0	−14	....	20	64	......
North Carolina	Asheville	Porters clay	5.8	10	53	19	9	16
Alabama	Perry County	Orangeburg clay	10.3	16	35	19	32	26
Louisiana	Caddo Parish	Miller fine sand	5.8	22	34	19	81	48
Texas	San Marcos area	Houston black clay.	8.1	6	26	19	25	32
South Carolina	York County	Iredell clay loam	7.7	3	17	18	51	19
Arkansas	Prairie County	Acadia silt loam	9.0	−11	41	18	32	21
Texas	San Marcos area	Houston black clay.	8.9	5	23	17	8	23
Indiana	Newton County	Marshall loam	7.6	22	21	16	77	34
Alabama	Lee County	Cecil sandy loam	8.6	10	28	15	.....	58
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	6.5	7	15	15	20	26
Arkansas	Prairie County	Acadia silt loam	7.3	14	37	15	7	16
Georgia	Waycross area	Norfolk fine sand	7.4	6	25	14	28	36
Mississippi	Pontotoc County.	Monroe silt loam	8.0	9	18	14	29	39
Texas	Nacogdoches	Orangeburg clay	8.6	4	5	14	29	5
Texas	Palestine	Orangeburg fine sandy loam.	11.4	−15	9	14	37	43
Mississippi	Montgomery County.	Memphis silt loam	7.0	13	17	14	36	40
Ohio	Westville area	Miami clay loam	6.1	7	11	13	15	45
Pennsylvania	Montgomery County.	Penn silt loam	12.3	−8	4	13	24	36
Mississippi	Montgomery County.	Memphis silt loam	8.6	6	9	13	6	34
Indiana	Tippecanoe County.	Marshall silt loam	7.2	−7	6	12	−2	4
New York	Tompkins County	Dunkirk loam	8.4	−7	11	12	46	0
Alabama	Perry County	Orangeburg sandy loam.	8.1	21	17	12	17	20
Mississippi	Montgomery County.	Memphis silt loam	10.2	1	20	12	18	28
New York	Tompkins County	Dunkirk clay loam	9.0	−14	12	11	68	−5
New York	Tompkins County	Miami stony loam	9.6	0	7	11	36	26
Florida	Escambia County	Portsmouth sand	8.3	48	48	11	47	35
Florida	Escambia County	Norfolk sand	5.4	46	74	11	83	107
Florida	Escambia County	Norfolk fine sandy loam.	8.4	35	14	11	32	51
Texas	San Antonio	Houston black clay loam.	5.8	11	19	10	19	−7
Pennsylvania	Montgomery County.	Hagerstown loam	10.3	6	23	9	20	29
Louisiana	Caddo Parish	Caddo fine sandy loam.	8.8	8	14	9	6	41
Louisiana	Caddo Parish	Norfolk fine sandy loam.	8.7	0	30	9	9	25
Texas	Rusk County	Susquehanna fine sandy loam.	7.0	−11	26	9	29	36
Ohio	Westerville area	Miami black clay loam.	8.3	1	11	8	22	5
Mississippi	Montgomery County.	Memphis silt loam	11.2	0	−3	8	5	9

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Louisiana	Caddo Parish	Caddo fine sandy loam.	6.0	19	16	8	79	23
Missouri	Crawford County.	Clarksville silt loam	6.6	14	1	7	43	32
Pennsylvania	Montgomery County.	Lansdale silt loam	9.9	19	17	7	9	30
New York	Binghamton area.	Dunkirk gravelly loam.	10.6	−3	−11	7	20	−9
Arkansas	Prairie County	Crowley silt loam	7.1	36	60	7	19	38
Indiana	Tippecanoe County.	Marshall loam	7.5	−3	7	6	42	−2
New York	Geneseo	Dunkirk clay loam	10.2	8	0	5	17	21
Wisconsin	Portage County	Marshall gravelly loam.	11.0	2	3	4	36	14
Louisiana	Caddo Parish	Caddo fine sandy loam.	5.0	8	72	4	44	148
Wisconsin	Portage County	Miami sandy loam	9.0	4	21	3	29	12
Wisconsin	Portage County	Portage silt loam	10.0	5	10	3	21	10
Missouri	Crawford County.	Clarksville stony loam.	14.6	−3	−2	3	−10	13
Arkansas	Prairie County	Crowley silt loam	10.1	2	5	3	7	9
Wisconsin	Portage County	Portage silt loam	8.7	9	−14	1	42	−14
New York	Binghamton area.	Dunkirk gravelly sandy loam.	6.6	26	27	1	29	69
Mississippi	Montgomery Co.	Memphis silt loam	10.6	−1	16	1	−4	6
Louisiana	Caddo Parish	Miller fine sand	7.3	14	16	1	43	36
Arkansas	Prairie County	Crowley silt loam	8.1	46	33	0	18	42
Arkansas	Prairie County	Morse clay	8.8	6	−7	0	6	22
Missouri	Crawford County.	Wabash silt loam	7.6	0	2	−1	23	24
Louisiana	Caddo Parish	Norfolk fine sandy loam.	9.6	6	19	−1	22	1
Arkansas	Prairie County	Morse clay	10.8	2	4	−3	4	9
Arkansas	Prairie County	Waverly silt loam	7.8	37	40	−3	18	41
Indiana	Newton County	Marshall fine sandy loam.	6.3	−12	−1	−4	60	−2
North Carolina	Statesville	Cecil clay (good)	8.8	5	....	−4	9	......
Ohio	Westerville area	Miami loam	8.6	2	2	−5	48	15
Mississippi	Montgomery County.	Memphis silt loam	9.5	−5	3	−5	−5	11
Ohio	Strongsville	Miami clay loam	....	30	....	−6	9	......
Illinois	Clinton County	Marion silt loam	7.7	−13	−4	−8	48	−12
Arkansas	Prairie County	Morse clay	11.1	−7	−1	−11	5	4
Indiana	Newton County	Clyde fine sand	12.6	−12	−7	−17	32	−4
Texas	Galveston	Galveston clay	11.2	−2	−8	−20	4	31

RELATIVE EFFICIENCY OF ORGANIC AND CHEMICAL MANURES.

An examination of Table VIII shows further the efficiency of manure and cowpea vines with lime as compared with a complete fertilizer with and without lime. In the majority of instances the manure or cowpea vines with lime, or both, have proved superior to the mineral fertilizers. A careful analysis of the results shows that manure and cowpea vines with lime nearly tie for first rank, while the complete fertilizer with lime ranks third, and without lime becomes fourth, or last. The relative number of times that each treatment ranks first on the basis of 100 for the whole is: Manure, 39; cowpea vines with lime, 39; complete fertilizer with lime, 16, and complete fertilizer alone, 6.

RELATIVE EFFICIENCY OF ALL SALTS AND COMBINATIONS WHEN SOILS ARE GROUPED ACCORDING TO EFFICIENCY OF PKN.

Table IX is an aggregation of the results in Table VIII and the results for the same soils in Table III and gives the average percentage increase in growth attributable to each ingredient and combination of ingredients for groups of soils in which the efficiency of a combination of nitrate, potash, and phosphate was within certain limits as given in the second column of the table. It also gives the average green weight of plants grown on the untreated soil for each of the groups as well as the weight produced by a complete fertilizer and the weight produced by the best average treatment for each group which in eight instances is attributable to cowpea vines with lime and in three instances to manure.

The efficiency of the single fertilizers, phosphate, potash, lime and nitrate, with a few exceptions increase in the order named, the phosphate being least effective and the nitrate most effective. In the group of soils for which the efficiency of a complete fertilizer is 60 to 69 per cent, potash outranks lime by 1 per cent, and in the following group it becomes identical with lime. In the last two groups in the table lime outranks the nitrate as well as potash and phosphate. A comparison of the efficiency of the several combinations of fertilizer salts and lime gives the order of efficiency that would be expected from a study of the relative efficiency of the same salts used separately. With a few exceptions, however, the efficiency of the various combinations is a little less than the aggregate efficiency of the same salts when used separately. These exceptions are mostly with the combination of potash and nitrate (KN), which in six out of eleven groups gives a larger percentage increase in growth than the aggregate of the same ingredients used separately. The efficiency order of the combinations, beginning with the smallest, is phosphate-potash (PK), phosphate-nitrate (PN), potash-nitrate (KN), phosphate-potash-nitrate (PKN), and phosphate-potash-nitrate-lime (PKNL). In the four lowest groups of the table, however, the potash-nitrate (KN) combination outranks the complete fertilizer without lime. A comparison of the most efficient fertilizer treatment, viz, that of the three fertilizing salts and lime, with the results obtained with manure and with cowpea vines and lime shows only four groups in which the fertilizer with lime outranks the manure and no instances in which the cowpea vines with lime have failed to outrank the fertilizer with lime. Of the eleven groups, cowpea vines with lime rank first eight times and manure three times.

In the last three columns is given the average green weight of plants on the untreated soil, with a complete fertilizer, and with the best average treatment, for each of the eleven groups of soil. It is noticeable that as there is a regular decrease in the efficiency of the fertilizers there is a corresponding regular increase in the weight of plants produced on the untreated soil. In other words, the lower the producing capacity of the soils the greater their response to fertilizers. The decrease in the efficiency of a complete fertilizer without lime is nearly inversely proportional to the increase in the weight of plants so that the weight of plants produced by the same fertilizer for any group of soils approaches a constant. The same is essentially true for the best average treatment with a tendency toward the largest plants on the poorer soils, as shown by the maximum weights of plants for the second and third groups from the top of the table under heading of best treatment.

TABLE IX.—*Average effect of fertilizer salts and combinations by groups according to the efficiency of PKN, also average weight of plants on untreated soil, average weight when treated with PKN, and average weight with best fertilizer treatment.*

Number of soils.	Range of efficiency.	Increase attributable to—											Weight of plants.		
		P.	K.	N.	L.	PK.	PN.	KN.	PKN.	LPKN.	Manure.	Cowpea vines and lime.	Untreated soil.	PKN.	Best treatment.
		P.ct.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Gms.*	*Gms.*	*Gms.*
5	100+	29	43	66	53	58	75	85	113	131	115	137	4.1	8.7	9.7
4	80–99	10	23	58	52	26	63	85	86	119	141	153	5.8	10.8	14.7
6	70–79	5	20	53	32	23	57	72	73	86	96	119	5.9	10.2	12.9
10	60–69	15	26	40	25	27	50	55	65	73	69	84	6.0	9.9	11.0
15	50–59	11	23	43	23	20	40	48	54	68	69	83	5.8	8.9	10.6
18	40–49	7	15	37	27	18	32	40	45	59	57	62	6.3	9.1	10.2
26	30–39	7	8	23	20	13	21	33	34	48	46	56	6.6	8.8	10.3
35	20–29	5	12	21	17	10	17	27	25	35	45	41	8.0	10.0	11.9
29	10–19	2	4	11	9	4	11	16	14	23	31	29	8.2	9.3	10.7
25	0– 9	1	5	6	8	2	6	12	5	15	24	26	9.0	9.5	11.3
13	−1 to − 20	−7	0	0	2	−7	2	7	−7	4	21	11	9.3	8.7	11.2

RELATIVE EFFICIENCY OF SALTS WHEN USED ALONE AND IN COMBINATION.

In these tests as shown in Table III, beginning on page 15, each of the three salts, acid phosphate, sulphate of potash, and nitrate of soda, has been used separately and in three combinations, thus giving four observations relative to the increase in growth produced by each. For lime there are two observations, while for manure and cowpea vines and lime there is only one observation each. While it is disputed ground as to whether the efficiency of a fertilizer salt should be measured by using it alone or by combining it with all other elements in which the soil may be deficient, many experimenters have adopted the combination as the most reliable means. It seems probable, however, that theoretical considerations, rather than observed results, have led to the adoption of such a system, the idea being that if the soil is deficient in two or more ingredients the full benefits of any one of them can not be obtained in the absence of a sufficiency of the others. While such reasoning seems logical it is not always supported by facts, as may be seen by a study of Table IV. Here there are only 20 soils out of 190 in which this seems to be noticeably true, while there is a much larger number, viz, 50 soils, in which the efficiency of the ingredients used separately is much more marked than when used in combination, and this in spite of the fact that all three of them produce quite marked results. Indeed, when we calculate the average efficiency of the ingredients for all soils we find that each is slightly more efficient when used alone than when in combination with one or more other ingredients.

As an average of many field tests on various crops and in numerous localities the conclusion is that the efficiency of a fertilizer ingredient is about equally as marked whether used alone or in combination with one or more other ingredients. On the less productive soils the tendency is toward a better effect from the ingredient when in combination with other ingredients which are also beneficial. On better soils the tendency is in the other direction.[a] For many individual soils this tendency is as marked under field conditions as it is in the pots.

Numerous bulletins of the Alabama agricultural experiment station report the results of fertilizer tests that were conducted at intervals during the years 1889 to 1900. Of such tests 156 were cooperative experiments with cotton and were carried on in 53 of the 67 counties of the State. The fertilizer materials used per acre consisted of nitrogen derived from 90 pounds of sulphate of ammonia or 96 pounds of nitrate of soda or 200 pounds of cotton-seed meal, potash derived from 150 or 200 pounds of kainit or 64 pounds of muriate of potash, and phosphorus derived from 195 or 200 pounds of dissolved boneblack or 240 pounds of acid phosphate. The three classes of fertilizer were used separately and the three were also combined, each ingredient entering into the combination in the same amount as when used alone. The results are reported in pounds of seed cotton per acre over and above that produced when no fertilizer was used, and the data for each of the three fertilizers when used alone and in combination are complete for 134 tests. The aggregate increase attributed to the three fertilizers when used separately was 443.2 pounds of seed cotton per acre, as compared with an average of 444.7 pounds increase per acre when the same ingredients were combined.

Table X shows the percentage increase in growth attributable to each ingredient when used separately, as compared with the calculated increase where it occurs in the several combinations. The results are for each of the four ingredients, lime, nitrate, potash, and phosphate, and are the averages for each of the 25 areas given in Table III. As an illustration of how the results are calculated, take the average results of the five soils from Cherokee County, S. C. Nitrate alone gave an increase of 40 per cent. Nitrate and phosphate produced an increase of 36 per cent, or 40 per cent more than phosphate alone, while nitrate and potash produced 49 per cent, or 42 per cent more than potash alone. The average effect for nitrogen in these two combinations is therefore 41 per cent and is entered in the second column under nitrogen. As NP = 36 and NK = 49, by addition (2N)PK = 85. However, PK = 3, so by difference we have 2N = 82 or N = 41, which is entered in the third column under nitrogen. NPK = 44 and since PK = 3, N in the NPK combination produced an increase of 41 per cent. The four values each for potash and phosphate and the two values for lime are obtained in the same manner. For this area the efficiency of the several ingredients is very uniform, the range of variation for nitrate, potash, and phosphate being only 1 per cent, while for lime the difference between the two observations is 7 per cent. Since the results in Table X are based upon the average of all soils from each area the variation in the efficiency of the ingredients as they occur in the various combinations is not marked. By making the same calculations for each of the soils, however, many of them show a marked variation in the efficiency of the ingredients as they occur in the several combinations, a difference far too great to be attributable to error of observation, which by actual test has been found not to exceed plus or minus 5 per cent. Where the variation in the efficiency of a fertilizer ingredient, as it occurs alone and in several combinations, exceeds the limit of error in observations as above stated, such portion of the variation as exceeds that limit must be attributable to its association with the other ingredients. Just as in a solution of several salts the presence of one may increase or decrease the solubility of others, so in the soil the addition of one ingredient may increase or decrease the effectiveness of another. It has already been shown that for quite a number of soils the effect of three ingredients combined is no better than for one of them and that one ingredient may be substituted for another with equally good effect. See Table VI, page 30. On the other hand, there are many soils in which the effect attributable to a combination of three fertilizer ingredients is two or three times greater than the aggregate effect of the same ingredients when used separately. See latter portion of Table IV, page 26.

---

[a] See tabulated results on corn in "Results in Field Experiments with Various Fertilizers," by Prof. W. O. Atwater, Ph. D., U. S. Dept. Agr., 1883.

The variation in the efficiency of a fertilizer ingredient as used separately and in several combinations bears no consistent relation to the efficiency of the ingredients with which it is associated or to the efficiency of the combination as a whole. If nitrate of soda produces an increase in growth which equals or exceeds that produced when it is associated with potash and phosphate, as is frequently shown in Table IV, page 26, we would theoretically expect little or no effect from either potash or phosphate when used alone on the same soils. Contrary to this theory, however, we find that, with an occasional exception, both potash and phosphate are markedly efficient on these soils. On the other hand, if nitrate of soda produces little or no increase as compared with a fair to good increase obtained when it is combined with potash and phosphate, as is frequently shown in the latter portion of Table IV, we should expect to obtain fair to good results from potash or phosphate when used alone on the same soils. But what do we find? Usually little or no effect from potash, and a negative effect from the phosphate. Table V, page 30, which is a condensation of the results in Table IV, shows up this relationship in a striking manner. In that table is given the average percentage increase in growth attributable to each of three ingredients and their combination for groups of soils in which the aggregate effect of the ingredients differs within certain limits from that obtained when they are used in combination. It will be noticed that there is a more or less regular and parallel decline in the efficiency of each of the ingredients when used separately, from a maximum of 37, 49, and 64 per cent for phosphate, potash, and nitrate to a minimum of -18, -5, and 2 for the same ingredients, respectively. Notwithstanding this marked decline in the efficiency of the ingredients when used separately, the efficiency for the three ingredients combined is essentially as marked at the end of the series as at the beginning, the average effect for the first and last groups being 52 and 53 per cent, respectively. The aggregate effect of the three ingredients used separately is 150 and -8 per cent for the same groups. (See Table V, p. 30.)

TABLE X. *Percentage increase in growth attributable to each fertilizer salt and lime, when used alone and when used in various combinations, as calculated by the difference method. Average, by areas.*

State.	Locality.	Increase with lime.		Increase with phosphoric acid.			
		L, alone.	PKNL−PKN.	P, alone.	$\frac{(PK-K)+(PN-N)}{2}$	$\frac{PK+PN-KN}{2}$	PKN−KN.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Indiana	Newton County	− 1	6	0	−6	− 6	−17
Missouri	Crawford County	4	− 3	6	2½	4	− 4
Ohio	Westerville area	3	3	− 3	4	4	− 4
New York	Tompkins County	2	− 9	− 5	−9	− 8	− 5
Wisconsin	Portage County	5	− 2	2	−2½	− 3½	− 2
New York	Binghamton area	11	− 1	4	1	0	− 5
Mississippi	Montgomery County	8	4	− 1	−1	− 4	− 4
Pennsylvania	Montgomery County	5	5	5	6½	4	− 5
Indiana	Tippecanoe County	2	− 9	10	9½	9	3
Missouri	Scotland County	11	0	7	0	3	− 4
Virginia	Hanover County	4	8	0	1	2	7
Texas	San Marcos area	14	4	8	0	8	8
Arkansas	Prairie County	26	26	5	−1½	2	− 1
Mississippi	Pontotoc County	16	6	10	−3	2	6
South Carolina	York County	15	8	8	−6	− 6	10
Louisiana	Caddo Parish	15	21	3	0	1	−11
Texas	Rusk County	13	7	6	−1	2	1
Tennessee	Henderson County	5	21	1	−8	−12	− 8
Kentucky	McCracken County	18	6	− 3	−4½	− 4	0
South Carolina	Cherokee County	18	11	− 4	−4	− 5	− 5
Alabama	Lee County	23	28	− 3	−5	− 4	2
Florida	Escambia County	52	35	8	−1½	4	− 1
Georgia	Waycross area	32	21	2	−1	0	0
Virginia	Louisa County	38	30	30	1	4	2
North Carolina	New Hanover County	40	19	14	7	9	5

State.	Locality.	Increase with potash.				Increase with nitrogen.			
		K, alone.	$\frac{(KP-P)+(KN-N)}{2}$	$\frac{KP+KN-PN}{2}$	KPN−PN.	N, alone.	$\frac{(NP-P)+(NK-K)}{2}$	$\frac{NP+NK-PK}{2}$	NKP−KP.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Indiana	Newton County	11	7½	10	− 1	4	1½	5	− 6
Missouri	Crawford County	6	1	1	− 7	4	2½	6	− 2
Ohio	Westerville area	5	5½	−1	− 9	4	10½	10	2
New York	Tompkins County	4	2½	6	9	21	17½	18	22
Wisconsin	Portage County	3	3	6½	8	12	9½	10½	12
New York	Binghamton area	7	5	5	0	6	8	12	7
Mississippi	Montgomery County	3	5½	5	5	8	12½	13	14
Pennsylvania	do	10	14	14	5	4	6½	5	− 5
Indiana	Tippecanoe County	8	4	0	− 6	14	17½	21	15
Missouri	Scotland County	24	16½	18	11	14	9	13	6
Virginia	Hanover County	8	9	10	19	16	16	16	25
Texas	San Marcos area	12	1½	6	6	23	11	14	14
Arkansas	Prairie County	10	3	6	3	12	5½	9	6
Mississippi	Pontotoc County	9	−1½	6	10	28	14½	20	23
South Carolina	York County	0	0	13	30	24	21	12	28
Louisiana	Caddo Parish	13	9	9	− 2	24	22½	25	14
Texas	Rusk County	11	6	11	10	32	24	26	25
Tennessee	Henderson County	1	6	16	20	36	29	28	31
Kentucky	McCracken County	3	7	13	7	39	33½	30	34
South Carolina	Cherokee County	7	8	8	8	40	41	41	41
Alabama	Lee County	6	5½	6	14	35	32½	32	39
Florida	Escambia County	19	7½	12	6	20	10	15	10
Georgia	Waycross area	15	14	16	17	45	42	42	43
Virginia	Louisa County	26	9	24	22	44	26	40	38
North Carolina	New Hanover County	21	17½	22	19	65	58½	60	57

RELATION OF FERTILIZER REQUIREMENTS TO CHARACTER OF SOILS.

That soils vary greatly in their crop-producing capacity and in the degree to which they respond to fertilizers under field conditions has long been known as a result of experience and also as a result of carefully recorded field tests. This marked difference in the degree to which various soils respond to fertilizer treatments is the most striking feature manifested in the results recorded in the preceding tables. It has also been long contended that there is a relation between the origin and the character of the soil and the character of the fertilizer that would be required to produce good results. It is doubtful, however, if such a claim can be substantiated by observed facts over a large territory. It certainly is not borne out by the results obtained on the 220 soils here reported, except in case of the muck soils which uniformly respond to potash. In fact, the character of the fertilizer

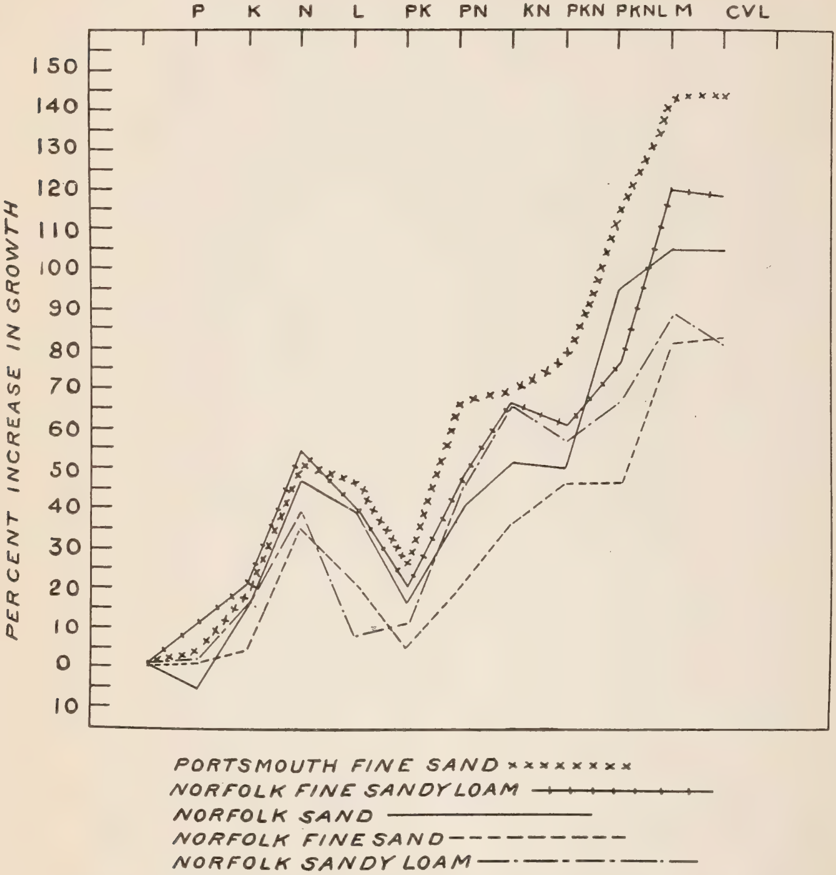


FIG. 1.—Percentage increase in growth of plants attributable to various fertilizer treatments of five principal soil types of the Waycross area, Georgia.

required for the same types or series of soils, as found in widely separated areas or localities, and as shown by these results, varies more than that required for different types and series when they occur in the same area or locality. In illustration of this point, five soils from Waycross, Ga., tested in triplicate, show a marked uniformity in the character of their manurial requirements, regardless of the fact that they represent five types and two soil series. The same soils in Escambia County, Fla., show manurial requirements of a very different character. (See Table III, p. 15, and figs. 1 and 2.)

In the Waycross area nitrate of soda is much more effective than sulphate of potash, and while lime is decidedly beneficial it is not equal to nitrate of soda. In Escambia County sulphate of potash is nearly as efficient as nitrate of soda, and lime is about twice as effective as the three fertilizer ingredients combined. These differences are based on average results for the two areas, and notwithstanding that the soils are of the same type, series, and formation, they show as marked differences in the character of fertilizer required as will be found between any of the areas, even when the soil types are entirely different.

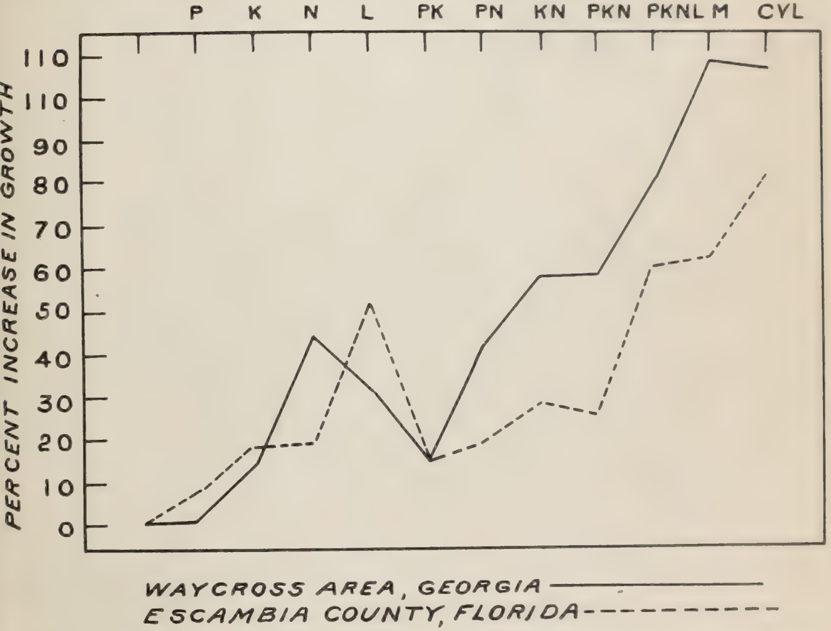


FIG. 2.—Percentage increase in growth of plants, attributable to various fertilizer treatments for soil of the Waycross area, Georgia, and Escambia County, Fla.

A Cecil sandy loam from Raleigh, N. C., was markedly improved by each of the three fertilizer salts, and also by lime, the increased growth of plants obtained when all of these ingredients were combined being 103 per cent. The same soil type from Lee County, Ala., as a result of tests on two samples, gave no response to either potash or phosphate, but produced a fair increase in growth as a result of nitrate of soda and also for lime, the maximum increase being 40 per cent where all three fertilizer salts were used in conjunction with lime. (See Table III, p. 15.)

RELATIVE EFFICIENCY OF FERTILIZERS BY LOCALITY.

In comparing the relative efficiency of the fertilizer ingredients, it is found that in the vast majority of instances nitrate of soda ranks first and lime second. This is especially true in the southern areas, where fertilizers are most extensively used. In the Central and Northern States, where the efficiency is less marked, there are quite a number of instances in which potash or phosphate outranks the lime or nitrate, although on an average the nitrate holds first rank and lime second. Sulphate of potash ranks next to lime, while acid phosphate having the lowest value, has in numerous instances shown a slightly negative effect.

With soils from the States of Wisconsin, Iowa, Missouri, Illinois, Indiana, Ohio, New York, and Pennsylvania the response to commercial fertilizers has been moderate, slight, or in many instances almost imperceptible. On those soils, also, organic manures, in the form of cowpea vines or stable manure, have been very much more effective than the chemical ones, the mean relative increase attributable to manure being nearly three times that for a complete fertilizer with lime, i. e., barnyard manure gave an average increase of 38 per cent, while the complete fertilizer with lime gave an average increase of only 13 per cent. (See Table XI, from which the averages were computed.) In these States lime alone seldom showed a marked effect. While the tests for these States are insufficient in number to represent all soil types and conditions, yet the results are in conformity with the general practices of the vast majority of farmers of these sections, who as a rule do not purchase commercial fertilizers for use in the growing of general farm crops, but who for the most part recognize the high value of barnyard manure and generally utilize all that is produced on the farm.

In the Atlantic and Gulf Coast States, including Kentucky, Tennessee, and Arkansas, for which a larger number of observations have been made and where most of the important soil types have been tested, the soils, with few exceptions, respond in a marked degree to commercial fertilizers and lime, and while cowpea vines and stable manure are on an average somewhat superior to commercial fertilizers, the differences between the relative value of these materials is small, being 54.7 and 58.6 per cent increase in growth for commercial fertilizers and manure, respectively, as compared with 13 and 38 per cent for the same materials in the former group of States. (See Table XI, from which these averages were computed.) In other words, the commercial fertilizers and lime are more than four times as effective on soils of the Altantic and Gulf Coast States as they are on those of the North Central States, including New York and Pennsylvania, while manure, when compared on the same soils, is only a half better on the soils from the former States. In this respect the results are again in conformity with the practices in the Atlantic and Gulf Coast States, where the bulk of the commercial fertilizers are used.

COMPARATIVE FERTILITY OF SOILS.

Another point brought out in the tables is the relative fertility or crop-yielding capacity of the untreated soils. Under the prevailing condition of crops and climate in the field, marked differences in this respect exist, some of the better soils showing a crop-producing capacity four or five times as great as that of the poorer ones. In these tests, where all soils are put into excellent physical condition and where moisture and temperature are always favorable, these differences are less marked but nevertheless exist to a considerable degree, as may be seen by comparing the actual weight of plants grown on the untreated soils. The average growth of plants on untreated soils from the North-Central States, including New York and Pennsylvania, is 28 per cent greater than the average of those from the Atlantic and Gulf Coast States. This difference in the initial crop-producing capacity of the soils from the two sections as indicated in the pots is sufficient to make the actual increase in growth from the stable manure nearly as great from one section as from the other.

TABLE XI.—*Increase in growth attributable to complete fertilizer with lime and manure; and proportionate cost of fertilizer to value of crops as obtained from Census, 1900.*

State.	Locality.	Weight of plants, untreated soil.	Increase from fertilizer and lime.	Increase from manure.	Cost of fertilizer to value of crop.
		Grams.	*Per cent.*	*Per cent.*	*Per cent.*
Missouri	Crawford County	9.6	0	19	0.23
Indiana	Newton County	8.8	4	56	.03
Ohio	Westerville area	7.8	8	28	.62
New York	Binghamton area	9.3	10	27	1.13
Wisconsin	Portage County	9.0	13	41	.32
Indiana	Tippecanoe County	6.8	16	37	.39
Mississippi	Montgomery County	9.3	18	18	.49
Pennsylvania	do	10.1	19	17	3.28
New York	Tompkins County	7.9	10	46	1.98
Missouri	Scotland County	9.6	28	69	.08
Texas	San Marcos area	8.5	32	26	.04
Mississippi	Pontotoc County	6.8	38	24	.03
Arkansas	Prairie County	8.3	40	21	.72
Virginia	Hanover County	7.5	41	38	4.04
South Carolina	York County	6.2	43	72	6.34
Louisiana	Caddo Parish	6.3	45	54	.21
Texas	Rusk County	8.0	45	67	.29
Kentucky	McCracken County	5.0	48	70	.22
South Carolina	Cherokee County	7.2	55	64	5.54
Tennessee	Henderson County	7.5	57	72	.10
Florida	Escambia County	6.3	61	63	6.82
Alabama	Lee County	6.4	70	65	4.81
Georgia	Waycross area	6.0	80	108	4.45
Virginia	Louisa County	5.9	96	44	4.50
North Carolina	New Hanover County	5.2	107	131	7.82

RELATIVE RESPONSE TO FERTILIZERS AND EXPENDITURES FOR FERTILIZERS.

In Table XI, where the average percentage increase in growth attributable to the complete fertilizer and lime is given for each area and arranged in an ascending series, there is also given the average percentage increase attributable to stable manure for the same soils as well as the expenditure for commercial fertilizers for the same areas or counties. The expenditure for fertilizers in the area is expressed in percentage of the valuation of products other than those fed to live stock and is computed from statistics reported in the United States Census for the year 1900.

This table, besides showing the relative response to the chemical fertilizer and stable manure, which was discussed in preceding pages, also brings out the relation between the response to a complete fertilizer and lime, as obtained by the paraffin pot test, and the expenditure for fertilizer in each county or area expressed in percentage of the valuation of crops produced.

The table is separated into two portions, the first portion embracing 13 areas or counties in which the increase in growth attributed to a complete fertilizer and lime ranges from 0 to 40 per cent, and the second portion embracing 12 areas or counties in which the increased growth for the same treatment ranges from 41 to 107 per cent. In the first portion of the table there are no localities where the valuation of commercial fertilizer used equals 4 per cent of the value of the products grown, while in the second portion there are only four localities where it does not exceed such percentage. In the first portion of the table where the response to the fertilizer with lime does not exceed 40 per cent there are only three localities where the cost of fertilizer actually used in 1900 exceeded 1 per cent of the valuation of the crop grown. These exceptions are in New York and Pennsylvania, in areas where special crops probably receive more attention than in the others. The one in Pennsylvania was immediately about Philadelphia. Their nearness to both the great produce and fertilizer markets is also a factor tending to the more extensive use of fertilizers.

Of the four counties in the second portion of the table in which the cost of fertilizers used does not exceed 4 per cent of the value of crops grown, McCracken County, Ky., and Henderson County, Tenn., are each represented by only one sample. If better represented, they would probably fall in the first portion of the table, as indicated by the small amount of fertilizer used. The remaining two counties are Caddo Parish, La., and Rusk County, Tex., in each of which cases but little commercial fertilizer is used, though they are grouped in the second portion of the table as a result of their response to fertilizers in the pot test. In these two counties the soils were well represented by the samples tested, and the results indicate that the moderate use of commercial fertilizer might prove profitable. There are other factors, however, besides the comparative response to fertilizers which are concerned in their profitable use. Low value of land, long distance from markets and seat of supplies, including fertilizer, would all tend

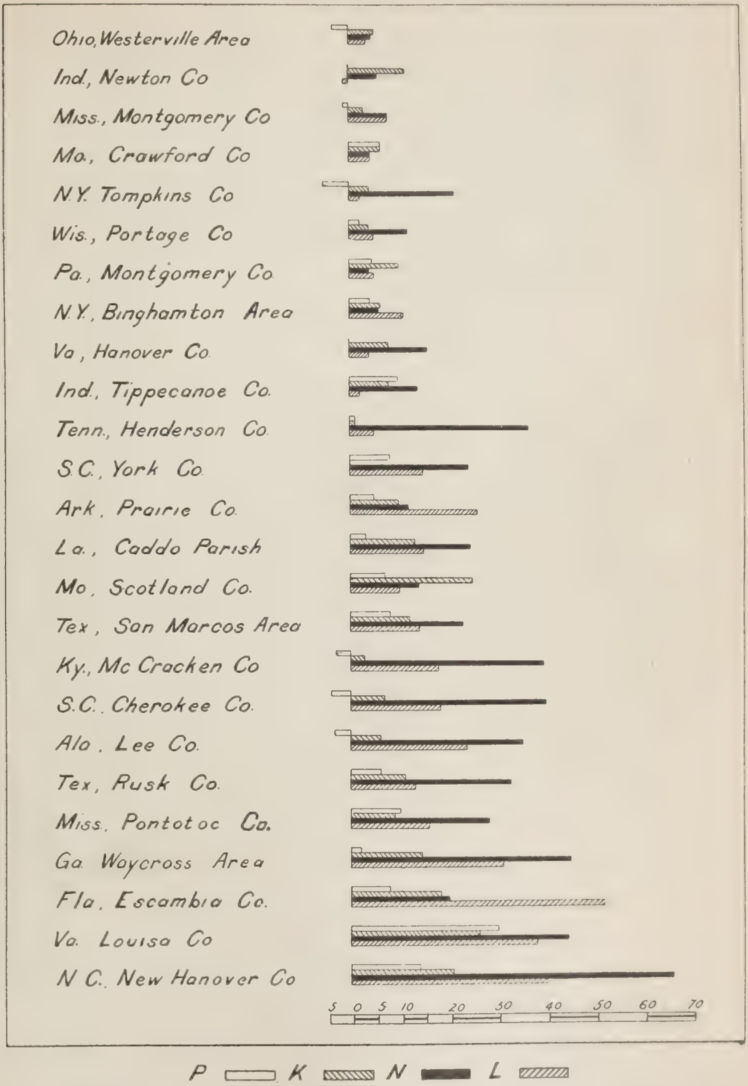


FIG. 3.—Percentage gain in plant growth attributable to each of the salts P, K, N, and L when used alone.

toward the unprofitable use of fertilizers. In Rusk County, Tex., and Caddo Parish, La., a few farmers have begun the use of commercial fertilizers and find them profitable.

AVERAGE EFFICIENCY OF FERTILIZER SALTS, BY LOCALITY.

Figure 3 shows graphically the percentage increase in growth attributable to each of the fertilizer salts and lime when used separately, and is based on the average for all soils of each area as given in Table X on page 43. The areas are arranged in an ascending series according to the aggregate increase from all ingredients, which ranges from a minimum of only 9 per cent for the Westerville area, Ohio, to a maximum of 140 per cent for New Hanover County, N. C. The range in the efficiency of the individual salts is also marked, the increase attributable to nitrate of soda varying from 4 per cent in several of the areas in the upper part of the diagram to 65 per cent in New Hanover County, N. C., and that for lime varying from a slightly negative result for Newton County, Ind., to an increase of 52 per cent for Escambia County, Fla., with somewhat lesser variations for potash and phosphorus. In the majority of the areas the efficiency of the three fertilizer ingredients and lime assume the same order. In 16 of the 25 areas, nitrate of soda was the dominant salt, while lime was dominant in 3 and potash in 3 of the areas. In 14 areas out of 25 lime ranks second in efficiency. In the States of Indiana, Missouri, Pennsylvania, and Virginia potash seems to have been relatively more effective than elsewhere. In the Arkansas and Florida areas lime is largely responsible for their position in the series, and in both of them nitrate of soda holds a relatively low rank.

TABLE XII.—*Average percentage increase in growth for all fertilizers and combinations, by soil series.*

Soil series.	No. of soils.	Weight of plants grown on untreated soil.	Increase in growth attributable to—										
			P.	K.	N.	PK.	PN.	KN.	PKN.		PKNL.	M.	CvL.
		Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Portsmouth	7	5.2	10	19	43	25	53	63	68	43	96	100	117
Norfolk	45	6.3	6	16	35	16	34	47	45	28	64	76	83
Cecil	12	6.0	14	12	36	17	32	46	52	26	69	62	65
Orangeburg	18	8.0	2	4	20	8	23	23	31	11	37	42	44
Miami	8	7.9	5	9	11	4	15	18	19	4	19	44	17
Marshall	5	7.0	5	8	16	6	10	20	12	4	8	50	8
Muck	4	6.0	21	62	27	56	33	49	60	30	60	46	39

TABLE XIII.—*Percentage increase in growth attributable to each fertilizer salt and to lime when used alone, as compared with its calculated effect when used in various combinations. Averages for each of six series and Muck.*

Soil series.	L.		P.				K.				N.			
	L, alone.	PKNL−PKN.	P, alone.	$\frac{(PK-K)+(PN-N)}{2}$	$\frac{PK+PN-KN}{2}$	PKN−KN.	K, alone.	$\frac{(KP-P)+(KN-N)}{2}$	$\frac{KP+KN-PN}{2}$	KPN−PN.	N, alone.	$\frac{(NK-K)+(NP-P)}{2}$	$\frac{NK+NP-KP}{2}$	NPK−PK.
Portsmouth	43	28	10	8	7½	5	19	17½	17½	15	43	43½	45½	43
Norfolk	28	19	6	−½	1½	−2	16	11	14½	11	35	29½	32½	29
Cecil	26	17	14	½	1½	6	12	6½	15½	20	36	26	30½	35
Orangeburg	11	6	2	3½	4	8	4	4½	4	8	20	20	19	23
Miami	4	0	5	−½	½	1	9	3	3½	4	11	9½	14½	15
Marshall	4	−4	5	−4	−2	−8	8	2½	8	2	16	8½	12	6
Muck	30	0	21	0	20	11	62	28½	36	27	27	−½	13	4

COMPARATIVE EFFICIENCY OF FERTILIZERS, BY SOIL SERIES.

Table XII gives the average percentage increase in growth attributable to each fertilizer salt and combination of salts, by soil series, using only those in which the treatments were uniform and complete. No series were used where less than 5 samples were available, except in the case of Muck, in which only 4 samples were used.

Table XIII gives the percentage increase in growth attributable to each of the three fertilizer ingredients and lime, as compared with their effect when used in the combinations, the efficiency in the combinations being calculated by the difference method previously explained. These two tables show that the relative efficiency of the three salts and lime is essentially the same for all the soil series except the Muck. The range of efficiency of the complete fertilizer with lime is very marked, varying from a maximum of 96 per cent for the Portsmouth series to only 8 per cent for the Marshall series. It is noticeable that barnyard manure is relatively much more efficient for the Marshall and Miami series than for the others.

Figure 4 shows graphically the average relative percentage effectiveness of the three fertilizer ingredients and lime by series when used separately, as given in Table XIII. The variation in the aggregate effectiveness of the three salts and lime for the several series is nearly as great as when the soils were grouped by localities. It is evident, however, that the serial grouping is, to some extent, a locality grouping also, the Marshall and Miami series, which are the least responsive to the commercial fertilizers, occurring only in those States in which fertilizers are but little used, while the Portsmouth and Norfolk series are confined wholly to the Atlantic seaboard, where fertilizers are most extensively used. While there is a marked difference in the aggregate effectiveness of the three salts and lime on different series, ranging from a minimum of 29 per cent for the Miami series to a maximum of 115 per cent for the Portsmouth series, broadly speaking the relation between the value of the individual ingredients in the several series is remarkably uniform, even more so than occurs when the soils are considered by areas. The Muck, represented by only 4 samples, is exceptional, and shows the characteristic importance of potash, that ingredient being on the average about as effective as the total of lime, nitrogen, and phosphate. This fact is also in conformity with our field knowledge of Muck and Peat, which are greatly benefited by applications of potash salts.

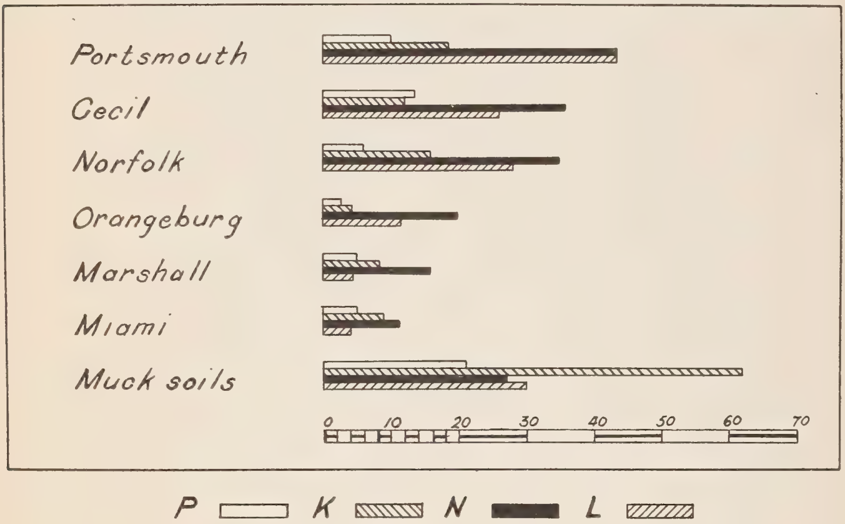


FIG. 4.—Relative efficiency of fertilizer ingredients by soil series, when the ingredients are used alone.

TABLE XIV.—*Average percentage increase in growth attributable to each fertilizer salt and lime for soils of the Norfolk, Portsmouth, Orangeburg, and Cecil series when classified by texture.*

Soil class.	Number of soils.	L.		P.				K.				N.			
		L, alone.	PKNL−PKN.	P, alone.	$\frac{(PK-K)+(PN-N)}{2}$	$\frac{PK+PN-KN}{2}$	PKN−KN	K, alone.	$\frac{(KP-P)+(KN-N)}{2}$	$\frac{KP+KN-PN}{2}$	KPN−NP.	N, alone.	$\frac{(NP-P)+(NK-K)}{2}$	$\frac{NP+NK-KP}{2}$	NKP−KP.
Coarse sand	2	14	9	−10	− 10	−4	7	8	5	8	19	34	26	24	35
Sand	12	43	33	7	−1.5	2	−1	16	10	16	13	42	32.5	35	32
Fine sand	17	33	21	5	2.5	3	3	15	13.5	15	15	37	35	36	36
Sandy loam	17	14	11	6	0	0	4	9	7	11	15	27	24	27	31
Fine sandy loam	25	22	13	8	3	5	0	13	8.5	10	6	27	23.5	26	22

EFFICIENCY OF FERTILIZER AS RELATED TO SOIL TEXTURE.

Table XIV gives the response to each of the three salts and lime when used alone and when in the various combinations for soils of the Norfolk, Portsmouth, Cecil, and Orangeburg series when grouped by the variation in texture. This grouping of the soil fails to bring out any variations in the character of the fertilizer required for the different textures, but it does show in general that the finer the texture of the soil, the less marked is the effect of the various fertilizer salts or the aggregate effect of them all.

NATURAL FERTILITY AS RELATED TO RESPONSIVENESS TO FERTILIZERS.

Another comparison brought out in the general tables is the relation between the crop-producing capacity of the untreated soils in the pots and their response to fertilizers. In general, the lower the crop capacity, the greater the response to fertilizers or manure, and vice versa.

Table XV shows the average effectiveness of a complete fertilizer and lime on soils arranged in groups according to the weight of plants grown when untreated, and it is shown that there is a gradual and consistent decrease in the effect of the treatment, as the untreated soils are capable of producing larger plants.

Table XV.—*Showing decreasing effect of fertilizers with increasing productiveness in untreated samples.*

Number of soils.	Weight of plants on untreated soil.	Average gain attributable to fertilizers.
	Grams.	*Per cent.*
23	3 to 4.9	87.9
35	5 to 5.9	68.3
25	6 to 6.9	41.8
46	7 to 7.9	40.1
33	8 to 8.9	23.9
19	9 to 9.9	26.8
9	10 to 10.9	13.0
9	11 to 11.9	8.4
7	12 and over	3.9

It is significant that the sandy soils of the Norfolk and Portsmouth series, collected from the Southern States where wheat is seldom grown, have produced on an average larger and more thrifty wheat plants by the application of a complete fertilizer and lime, than have been produced by the same or other treatments on soils of the Marshall or Miami series from Wisconsin, Ohio, Indiana, and New York, where wheat does well. This fact is in harmony with the view now gaining prevalence, that the variation in the character and composition of the mineral matter of soils is of minor importance as regards crop adaptation and yielding capacity, except so far as character of material influences condition of the soil in its relation to soil moisture and permeability to air, water, and the roots of plants. In other words, crop adaptation and crop-producing power depend more upon climatic environment and physical condition of the soil than upon soil type or the geological formation from which it is derived. The best wheat soils or those best suited to peaches or to truck crops are not so solely by virtue of the character of the mineral matter of which they are composed, but because there are present climatic and soil conditions that enable those classes of plants to attain perfection.

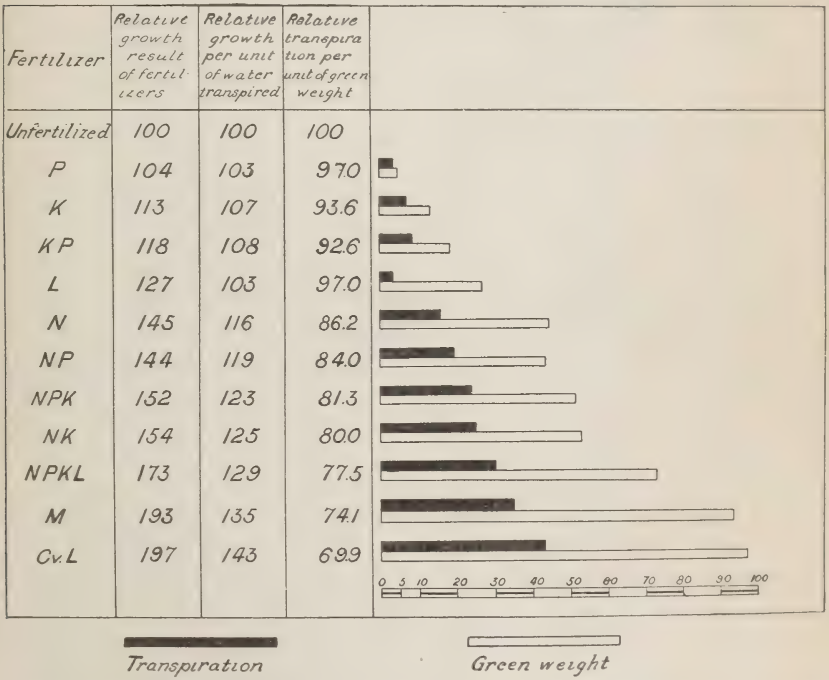
The poorest soils, by proper manipulation and the addition of suitable manure or fertilizer, can be made to produce as large yields in the pots as can be procured by the same or other treatments on the best soils that occur, and yet such applications have but slightly altered the composition of the soil. Such improvement does not involve any considerable length of time, but may be brought about in a few days or at most a few weeks. This does not mean that it would be either feasible or practical to attempt such a radical change under field conditions in so short a time. The expense involved would not justify the procedure, neither would the soil be able to maintain such an ideal condition under the adverse climatic conditions which might prevail or against the poor systems of farming in vogue. The improvement of soil conditions in the field becomes a purely business proposition in which the expense involved must not exceed probable returns.

Important in this connection is the assembling and association of all those factors that will work together for the good of the soil, such as the selection of suitable crops, the use of a proper rotation, the adoption of catch and winter cover crops, and cultivation of such character that erosion will be reduced to a minimum and the rainfall absorbed and retained in ample supply. By such procedure the condition of a soil will in time become greatly modified and its fertility improved. So-called soil robbery is, after all, more properly soil mutilation, brought about by the carelessness of man.

FERTILIZERS AND ECONOMY OF WATER IN PLANT GROWTH.

It has been stated that no attempt will be made to explain how fertilizers effect an increase in plant growth, yet there is one point which has been established as a result of this investigation of which mention should be made. It is the relation between growth, as effected by fertilizers, and water transpired by the plants or used in the process of their growth. In all of the tests a careful record has been kept of the water transpired for each of the 13,000 or more pots. As a result of such observations, it has been found that as fertilizers increase plant growth, there is a marked diminution in the water transpired per unit of growth; or, putting it in the reverse order, there is a marked increase in growth for a unit of water used, and such increase becomes greater as the fertilizers are more effective. As a result of computations for twenty soils taken at random, it was found that the percentage increase in growth for a unit of water used equaled, approximately, one-half of the total increase in growth resulting from the fertilizer treatments.

Figure 5 gives the average results for 20 soils and shows not only the gain in growth following the fertilizer treatments, but also shows the associated increase in growth per unit of water transpired.



Fertilizer	Relative growth result of fertilizers	Relative growth per unit of water transpired	Relative transpiration per unit of green weight
Unfertilized	100	100	100
P	104	103	97.0
K	113	107	93.6
KP	118	108	92.6
L	127	103	97.0
N	145	116	86.2
NP	144	119	84.0
NPK	152	123	81.3
NK	154	125	80.0
NPKL	173	129	77.5
M	193	135	74.1
Cv.L	197	143	69.9

FIG. 5.—Percentage increase in growth of plants attributable to fertilizer and accompanying increase per unit of water transpired. Average of 20 soils.

Excepting lime, in the presence of which transpiration remains nearly normal, the different fertilizer constituents show no marked variation in respect to this phenomenon. Lime frequently produces an increase in growth and yet the plants maintain practically the same rate of transpiration per unit of growth as that observed for the untreated soil.

In a few miscellaneous tests, where the different forms of potash were tried, it was found that kainit and muriate of potash decreased the rate of transpiration per unit of growth, as compared with sulphate of potash.

While these observations have no economic significance in the pots where moisture content is always ample, they may be of considerable importance in relation to the use of fertilizers in the field and explain, in part, the benefits derived therefrom. It frequently happens, owing to scanty rainfall, or a low water-holding capacity of the soil, that the available water supply is the limiting factor in crop yields. Where such conditions exist, and they occur frequently in all parts of the country, the presence of a fertilizer which would enable the crop to economize in its water consumption would be of considerable importance and might, as pointed out above, enable the crop to make a marked increase in growth despite the limited water supply.

SUMMARY.

The paraffin-pot method of testing the manurial requirements of soils, used in these investigations, while not designed to supersede field tests, is admirably adapted to an investigation of this kind and is very useful as a method of indicating what fertilizers should be used in the field.

The results obtained in the pots with the various ingredients are relatively the same as those obtained in the field, but may differ in degree. This is true of all ingredients commonly used except the phosphates, which give a relatively lower effect in the pots than the others. The absolute effect is usually greater in the field than in the pots and phosphates may frequently be economically used where their benefits are not indicated by the pots.

The results obtained in the pots generally agree with the fertilizer practices in the various sections from which the soils were secured. In the North Central States, where but little commercial fertilizer is used, and where the main dependence is placed upon barnyard manure, the pot tests show manure to be three times as efficient as the fertilizer. In the Atlantic seaboard and Gulf Coast States, where but little manure is available, and where the main dependence is upon commercial fertilizers, the manure as tested in the pots has been only slightly superior to the fertilizers. Muck, quite generally recognized as in need of potash in the field, has shown that ingredient to be nearly as efficient as lime, nitrate, and phosphate combined, as determined by the pot tests.

Transpiration, while a good indicator of the relative growth of plants when under like conditions, usually gives a range of lesser magnitude than the variation by green weights.

The green weight of plants grown for about twenty-five days in the pots occasionally equals or exceeds 1 per cent of the weight of the soil in which they grew. Such plants contain about 85 per cent of water and transpire approximately 100 grams of water for each gram of green matter produced. The dry matter of such plants is richer in mineral constituents and nitrogen than that of the same plants if matured. The draft on the water and mineral constituents of the soil under these conditions is greater than that occasioned by the removal of a large and matured crop under field conditions.

As an average of all tests, the organic manures have outranked the chemical ones. Barnyard manure and cowpea vines with lime tie for first rank. The three chemical salts with lime rank third and the same salts without lime rank fourth.

Of the combinations of chemical salts the order of efficiency is as follows: The three salts with lime, first; three salts alone, second; potash and nitrate, third; phosphate and nitrate, fourth, and phosphate and potash, fifth.

Of the salts used individually the order is nitrate, lime, potash, and phosphate; nitrate being the most efficient and phosphate the least efficient.

As an average result of all tests, nitrate of soda has produced a marked increase in growth which has not been further increased by the addition of acid phosphate. Potash has produced a moderate increase in growth and when supplemented by nitrate the effect has been slightly less than the aggregate of these two ingredients when used separately. The efficiency of the combination of nitrate and potash has not been appreciably improved by the addition of phosphate.

Lime alone has generally produced a marked increase in growth and has usually increased the efficiency of a complete fertilizer. There is but little evidence that the benefits derived from lime are due to beneficial action on nitrification.

Soils vary greatly in crop-producing capacity as found under field conditions. Part of such variation is due to physical condition and consequent relation to water, and is largely overcome in the pots. After these conditions are largely equalized in the pots marked differences in crop-yielding capacity still exist to such an extent that good soils may produce four or five times as large a growth as that produced on very poor soils under the same conditions. By the application of suitable manures or fertilizers these differences are overcome, and in the pots the poorest soils when treated with suitable substances become as productive as the best ones.

Soils vary greatly in the degree to which they respond to commercial fertilizers, lime, manure, and green manure. In general, the degree of response varies inversely as the crop-yielding capacity and ranges from zero to several hundred per cent. The soils of the Atlantic and Gulf Coast States are much more responsive than those of the Central and Northern States.

In 60 per cent of the soils here tested, each fertilizer salt appears to have a special function, so far as it influences the growth of plants, which is not materially modified by the addition or withholding of the other salts. In 29 per cent of the soils the functions of the several salts, as affecting the growth of plants, are more or less interchangeable, there being quite a number of instances when each salt used alone gave as large an increase in growth as was secured by combining three of them. In 11 per cent of the soils each salt not only has a distinct function, but it is dependent upon the presence of others for its fullest effect as shown by a much greater efficiency when used in combination than when used alone. There is no apparent relation either by soil type or by locality to this grouping of the soils.

The variation in the efficiency of a fertilizer salt as used alone and in combination with various other salts bears no consistent relation to the efficiency of the associated salts or to the efficiency of the combination as a whole.

In the pots, as an average of all tests, the aggregate efficiency of the several salts when used separately is slightly greater than when the same salts are used in combination. Under field conditions, as an average of many tests, the aggregate of individuals is the same as when used in combination. Individual soils show wide variation in respect to this point.

The character of fertilizer indicated for a specific soil type as it occurs in widely separated localities usually varies more than that for very different types when in the same locality and subjected to similar environment.

The character of fertilizer indicated for various soil series is essentially the same, although the response to such a fertilizer varies greatly.

In general, the finer the texture of soils the less responsive are they to fertilizers, although the character of fertilizer indicated remains the same.

With few exceptions the character of fertilizer required for soils depends more upon local conditions and practices than it does upon the type of soil or the geological formation to which it belongs. The Muck soils are an exception and show a universal response to potash salts.

The condition of the soil is of greater importance than its chemical composition.

Without materially changing the composition of the soil, poor soils by proper manipulation and suitable applications can be made to produce as large crops in the pots as can be grown on the best soils by the same or other treatments.

Fertilizers when effective aid plants to economize in the use of water.

In conclusion it may be said that the crop-yielding capacity of soils is increased by improving their physical condition and by supplying manures or fertilizers. Frequently both are necessary, and the latter may assist the former. By the employment of both methods poor soils may become as productive as the best ones. There is but little to indicate any relation between the formation and character of the soil and character of fertilizer to which it will respond. Usually soils of a limited locality, where climatic condition and farm practices are uniform, show but little difference in the character of fertilizer required, although the degree of response may vary greatly for different fields, making their use profitable in some instances and unprofitable in others. Except in the most general way, the fertilizer requirement of soils becomes a problem for each farm or for each class of farms under like conditions of soil, climate, and system of cropping and fertilization. The indications are that fertilizers containing relatively more potash and nitrogen than do those now in general use would prove more effective. This conclusion (to which exception might be taken by some because of the fact that phosphates are known to be economically used on some soils that fail to respond to that salt in the pots) is not based alone on the result of this investigation, but upon the tendency of the more progressive planters to use a higher grade fertilizer, i. e., one containing relatively more nitrogen and potash than that used in the past. Lime has proved quite generally beneficial, being on an average more effective than both potash and phosphate.

O